UNIVERSITY OF ILLINOIS

June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

OSCAR JOSE SUMAY

ENTITLED THE DESIGN OF AN HYDRO-ELECTRIC POWER PLANT ON THE VERMILION RIVER AT DANVILLE, ILLINOIS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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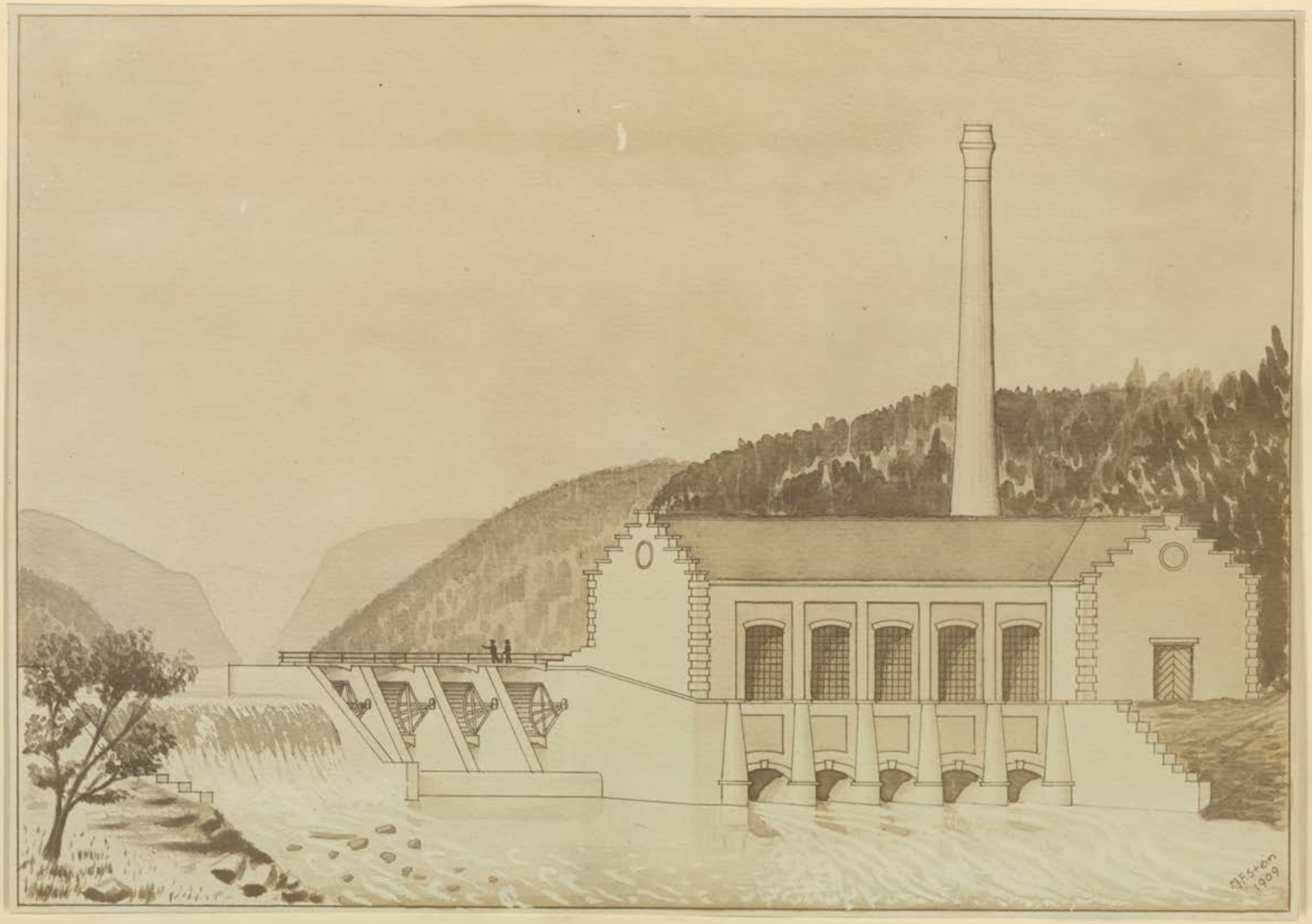

DANVILLE HYDRO ELECTRIC PLANT — PERSPECTIVE VIEW

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INTRODUCTION.

As a result of the present universal interest in the conservation of national resources, much has been written and some little has been done with respect to utilizing the latent power of our rivers and streams. Perhaps the attitude of many writers, especially of those catering to the popular taste, has been too sanguine. And this may naturally be expected, since the subject, when treated with the aid of a little imagination, a not too scrupulous searching into facts, and a few well selected illustrations of raging torrents, cannot but give the average reader the impression that water power development must be one of the most direct and successful means of deriving from nature some of her superabundant energy, and applying the same toward the benefiting of mankind. While this is not strictly true, especially when applied to specific streams rather than to streams in the abstract, it is nevertheless certain that water power developments will play an important part in our future economic development, and are deserving of carefuly study by the coming generation of engineers.

It was the purpose of the writers in choosing this subject for their thesis to become familiar with some of the important principles of this branch of engineering and their applications, rather than to design a plant which should be of high merit from an engineering stand point and very successful when financially considered. However much lacking the design may be from the latter point of view, its execution has nevertheless brought up many interesting and suggestive questions as to streamflow, the financial and economic side of building and running power plants , methods of hydraulic construction, etc., which should prove of great value to the writers. It will undoubtedly also be valuable, as every design thesis should be, in affording a basis of comparison for questions arising in connection with future work.

As far as possible, all the work was done together, each of the writers assuming the lead in the part relating more particularly to his course of study. The surveys were not as complete as should be the case, owing to the lack of time and the season of the year during which they had to be made. The stream flow was carefully worked up from the data of neighboring streams, the aim being to select streams with analogous conditions for comparison. The financial side of the question was rather fully investigated, following in form, if not in completeness, that which should precede an important project of this nature. In the design, some minor details have been merely mentioned, or but briefly described, but all important points have been computed with care. Owing to lack of time, the construction has hardly been touched upon, excepting as indicated in some of the drawings.

In writing up the thesis, it has been divided into two parts, the first being in the form of an enginaer's report and relating to the preliminary investigation, probable financial results, estimate of cost, and other matters of interest to the persons promoting the enterprise, while the second describes the work as completed, giving the methods by means of which the results were obtained.

The writers here desire to express their acknowledgment to

Professor D. W. Mead, for valuable advise concerning method of working up stream flow data, to Thomas W. Orbison, hydraulic engineer, for suggestions as to the form of report, to Mr. O. E. Selby, bridge engineer of the Cleveland, Cincinnati, Chicago and St. Louis Railway, for data on borings made along the Vermilion River, and to Mr. W. A. Van Frantz, division engineer of the Frisco System, for records of flood flows on this stream.

REPORT ON THE WATER POWER OF THE WABASH - VERMILION RIVER AT DANVILLE , ILLINOIS.

DESCRIPTION OF THE VERMILION RIVER: The Wabash - Vermilion River rises in Ford County, Illinois, at a point some fifteen miles north - west of the town of Paxton, and flows in a general south-easterly direction, entering the Wabash River at point five miles east of Cayuga, Indiana. The total length of the river is about 85 miles, of which only seven miles are in Indiana. The river has two important branches: Salt Fork, which drains the western and southern portion of the drainage basin, and North Fork, which drains a small area in the eastern part of the drainage basin. The area drained by Vermilion and its branches comprises a compact, almost rectangular portion of central Illinois, some 1500 square miles in extent. The elevation of the source is approximately 800 feet above sea level, while the mouth has an elevation of but 465 feet, making a total fall of 335 feet or an average fall of 3.95 feet per mile. This fall is not uniform thru-out the length of the river, but decreases from source to mouth.

The country drained consists almost entirely of fertile prairie composed of glacial till of the early Wisconsin glaciation with a covering of from 16 to 20 inches of "brown silt loam" - a porous, dark - colored soil which has a great capacity for absorbing and retaining water. The land is mostly under cultivation, there being no swamps or lakes, and no timber except in the immediate vicinity of the streams. Owing to these conditions,which offset advantage of a porous soil, the stream flow is subject to large fluc-

Plate No. 1.
DANVILLE HYDRO ELECTRIC PLANT
DRAINAGE AREA
of the
VERMILION RIVER
Thesis of Sumay & Stein

tuation, being very large in the spring and early summer, and small in the autumn.

The stream is evidently of post-glacial origin, and as the time since the glacial recession has been short-geologically speaking- it has not reached its base level, and - especially in the lower part of its course - flows thru a narrow valley, with steep bluffs from 50 to 80 feet in height on either side.

Table 1 shows in tabular form the length, area drained, per cent of land cultivated, etc., for the different branches of the Vermilion River and for the whole river.

Table 1.

Stream	Length miles	Area sq. m.	Per Cent cultivated	Per Cent timbered	Per Cent water surface.
Salt Fork	45	510	97.8	2.0	0.20
Middle "	60	540	97.7	2.2	0.16
North "	46	292	97.3	2.4	0.29
Vermilion below N. Fork	18	145	94.3	5.0	0.70
Total	85	1480	97.0	2.7	0.25

STREAM FLOW: As there have been no stream measurements made on the Vermilion River, it is impossible to obtain exact data as to the stream flow. Moreover, in the limited time at our disposal, it would have been useless to make gaugings of the stream, as such measurements to be of value should extend over a series of years. The stream flow will therefore be estimated from the rainfall and other concomitant factors and by comparison with similar streams.

Stream flow depends:

1. On the amount of rainfall.
2. On the topographical conditions, especially on the slope of the land surface.
3. On the geological conditions, especially on the character of the soil and subsoil.
4. On the degree of cultivation of the land, whether it is farming country, timbered land, etc..
5. On the season of the year.
6. On climatical and meteorological conditions such as temperature, humidity, air pressure, etc..

All these factors make the question of estimating streamflow an extremely complex one . There are, however, several methods of computing the streamflow approximately from rainfall records. One of them is to consider a certain percentage of the rainfall as constituting the streamflow. This has been carefully investigated by Emil Kuichling*. He has plotted the measured monthly runoff and the corresponding monthly rainfall for a large number of eastern rivers and has constructed curves giving the relation of rainfall and runoff for each month. Another method has been developed by C. C. Vermeule#.In this case the runoff is taken as being that part of rainfall which does not evaporate; part of this runoff, however, being considered as stored in the ground during the spring (when excessive rainfall occurs) and supplementing the stream flow during the summer and autumn.

* Report of N.Y. State Canal Survey.

\# Geological Survey of New Jersey, 1894, 3.

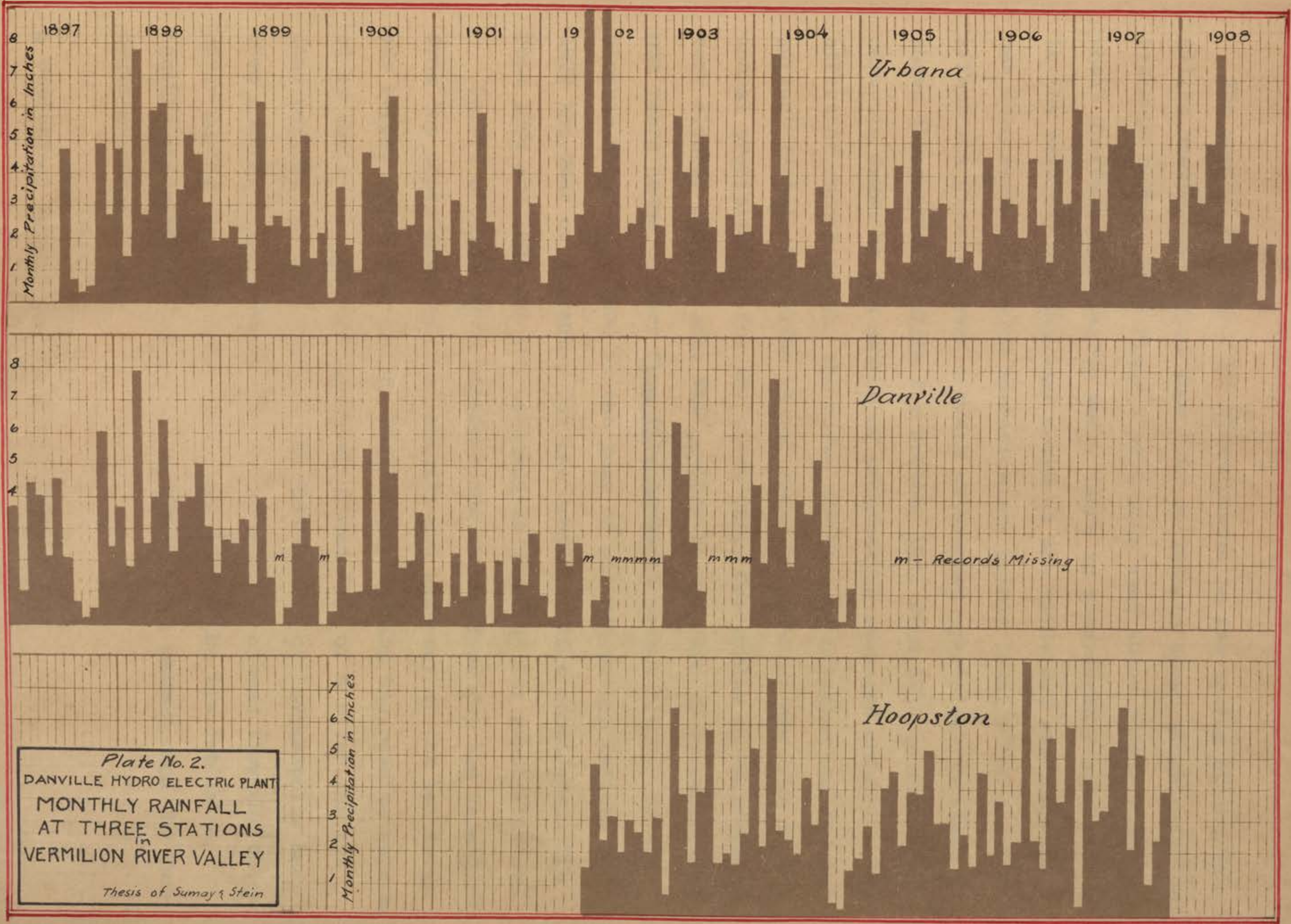


Plate No. 2.
DANVILLE HYDRO ELECTRIC PLANT
MONTHLY RAINFALL
AT THREE STATIONS
in
VERMILION RIVER VALLEY

Thesis of Sumay & Stein

The monthly rainfall for three points in the valley of the Vermilion during the period from 1897 to 1908 is shown graphically on Plate 2. Reference to Plate 1 will show that these points cover the whole drainage area fairly well. There is considerably variation in the rainfall for the same month at the different stations but has been shown that such variations are purely local -"too local to affect the yield of even a small water-shed appreciably"*. Plate 3 shows the yearly rainfall for Urbana, Ill. from 1889 to date. The curve is drawn by the method of progressive averages which has the effect of smoothing out the curve and thereby bringing out the important variations, altho it may cause an error of one inch in the annual precipitation for any given year. The cycles of rainfall are very clearly brought out. The periods between two consecutive minimum years seems to vary from five to eight years. A study of the diagram shows that 1894 is the year of minimum precipitation, and 1898 the year of maximum , for the length of time considered. The year 1904 and 1905 are two consecutive years of low precipitation.

Before attempting to estimate the stream flow for the Vermilion from the above data, the reliability and accuracy of the two methods before mentioned will be tested by comparing the results obtained by their use with the measured stream flow of a river for the same period. For this purpose the White River of Indianapolis has been chosen. Plate 4 shows the actual monthly stream flow for this river during the year 1904, 1905, and 1906, also the estimated monthly stream flow as computed by Kuichling's method, and by Vermeule's method.

* Geological Survey of New Jersey 1894.

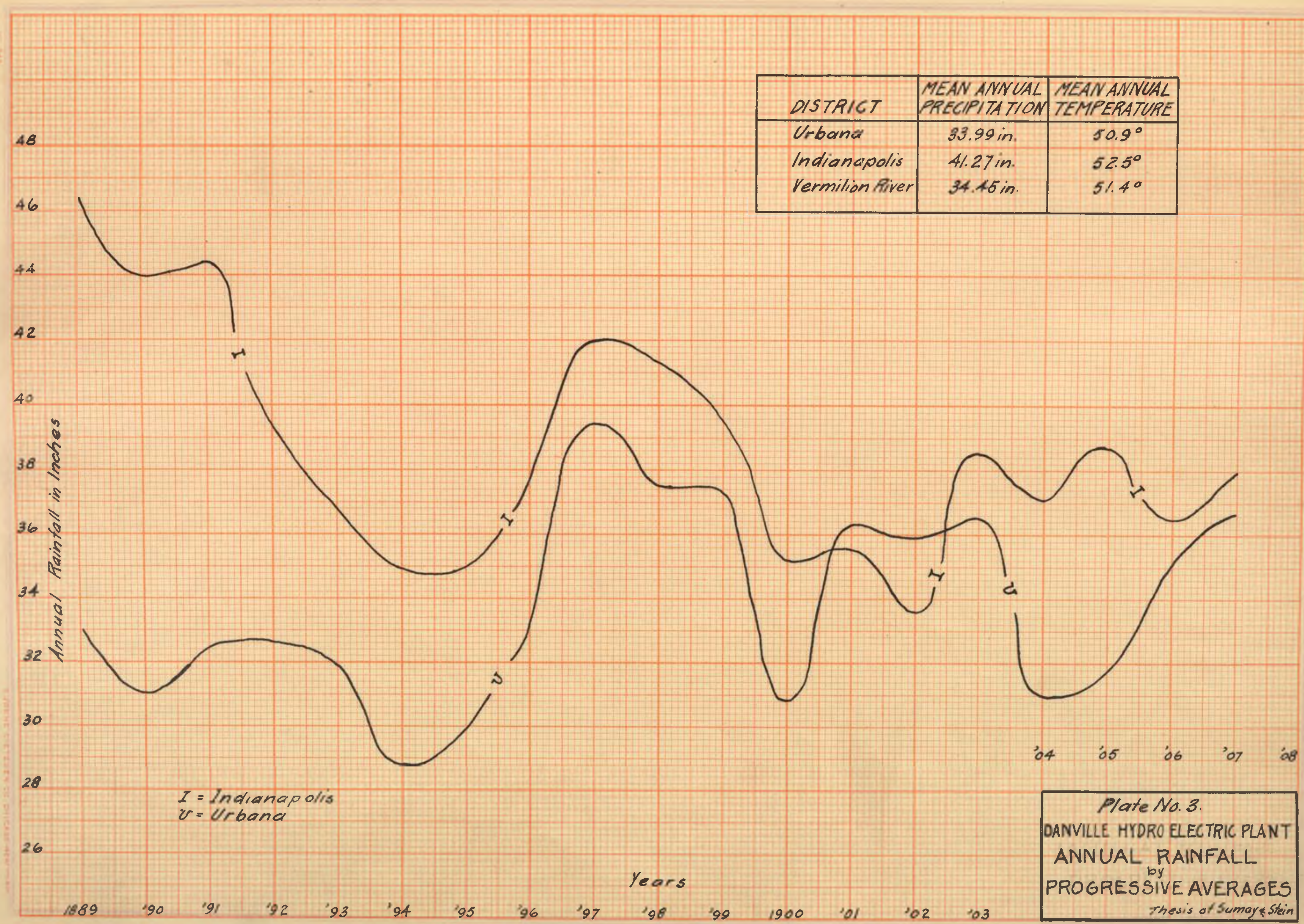
Plate No. 3.

DANVILLE HYDRO ELECTRIC PLANT

ANNUAL RAINFALL by PROGRESSIVE AVERAGES

Thesis of Sumay & Stein

DISTRICT	MEAN ANNUAL PRECIPITATION	MEAN ANNUAL TEMPERATURE
Urbana	33.99 in.	50.9°
Indianapolis	41.27 in.	52.5°
Vermilion River	34.45 in.	51.4°



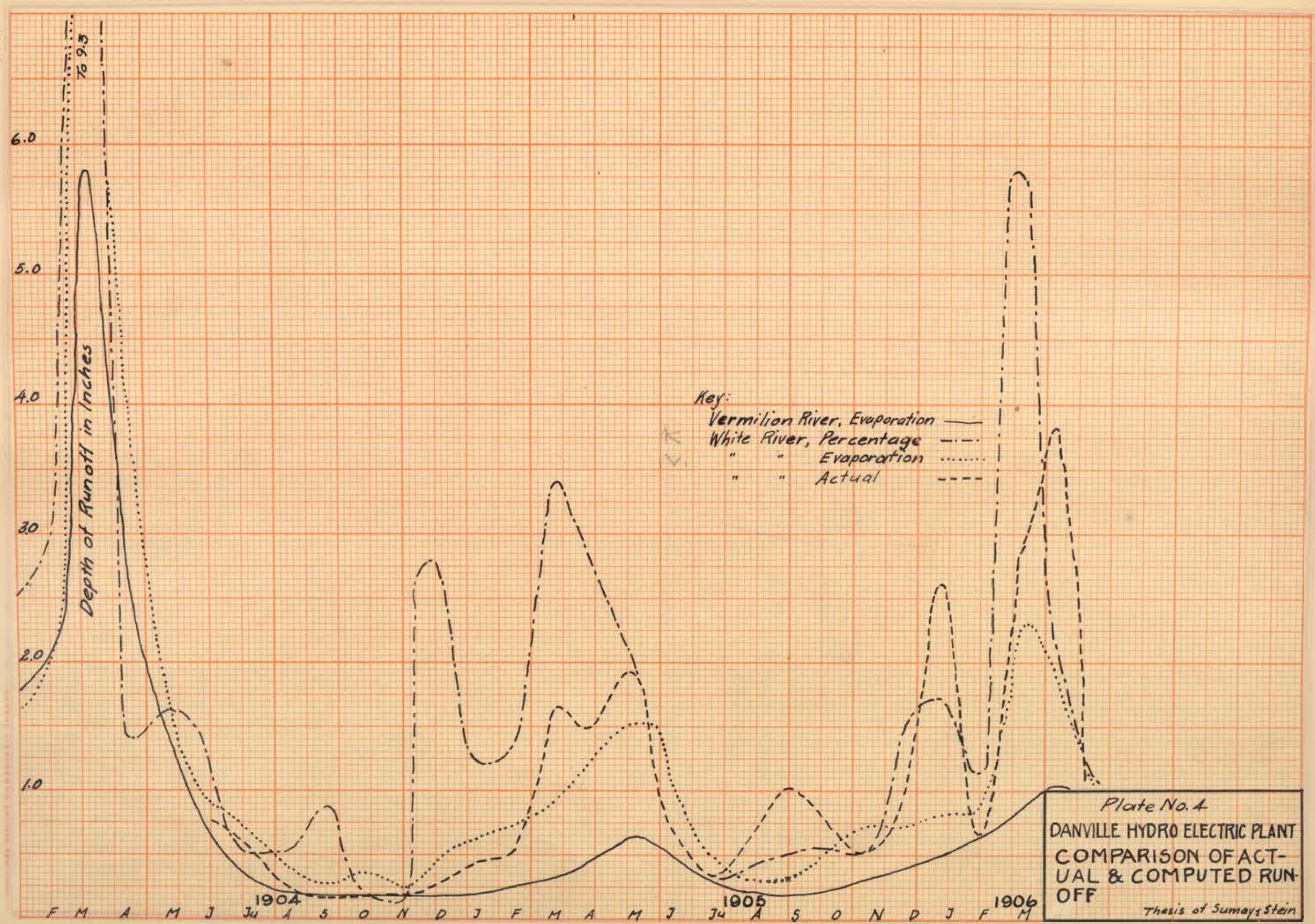


Plate No. 4

DANVILLE HYDRO ELECTRIC PLANT

COMPARISON OF ACTUAL & COMPUTED RUN-OFF

Thesis of Sumay & Stein

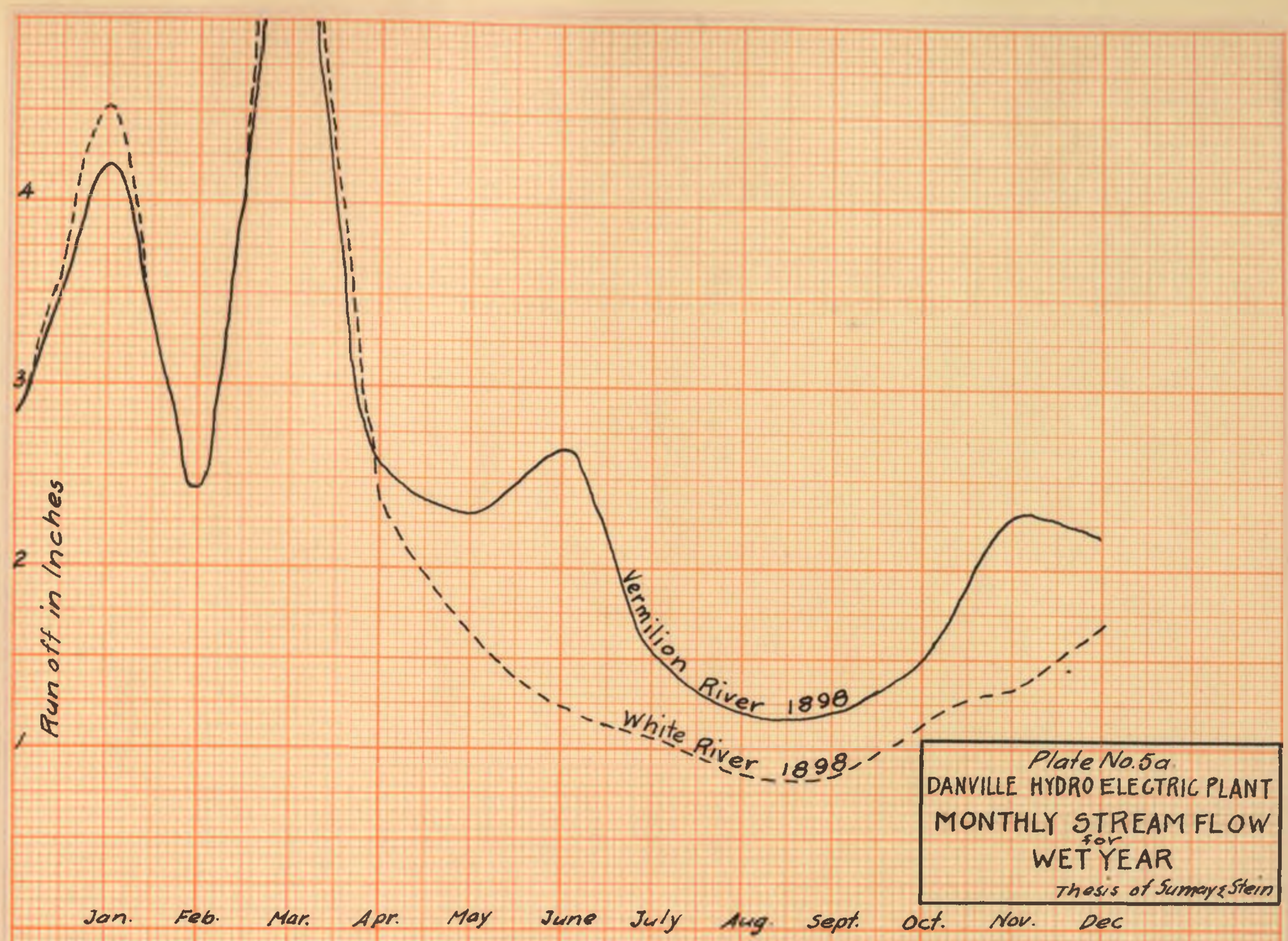


Plate No. 5a
DANVILLE HYDRO ELECTRIC PLANT
MONTHLY STREAM FLOW
for
WET YEAR
Thesis of Sumay & Stein

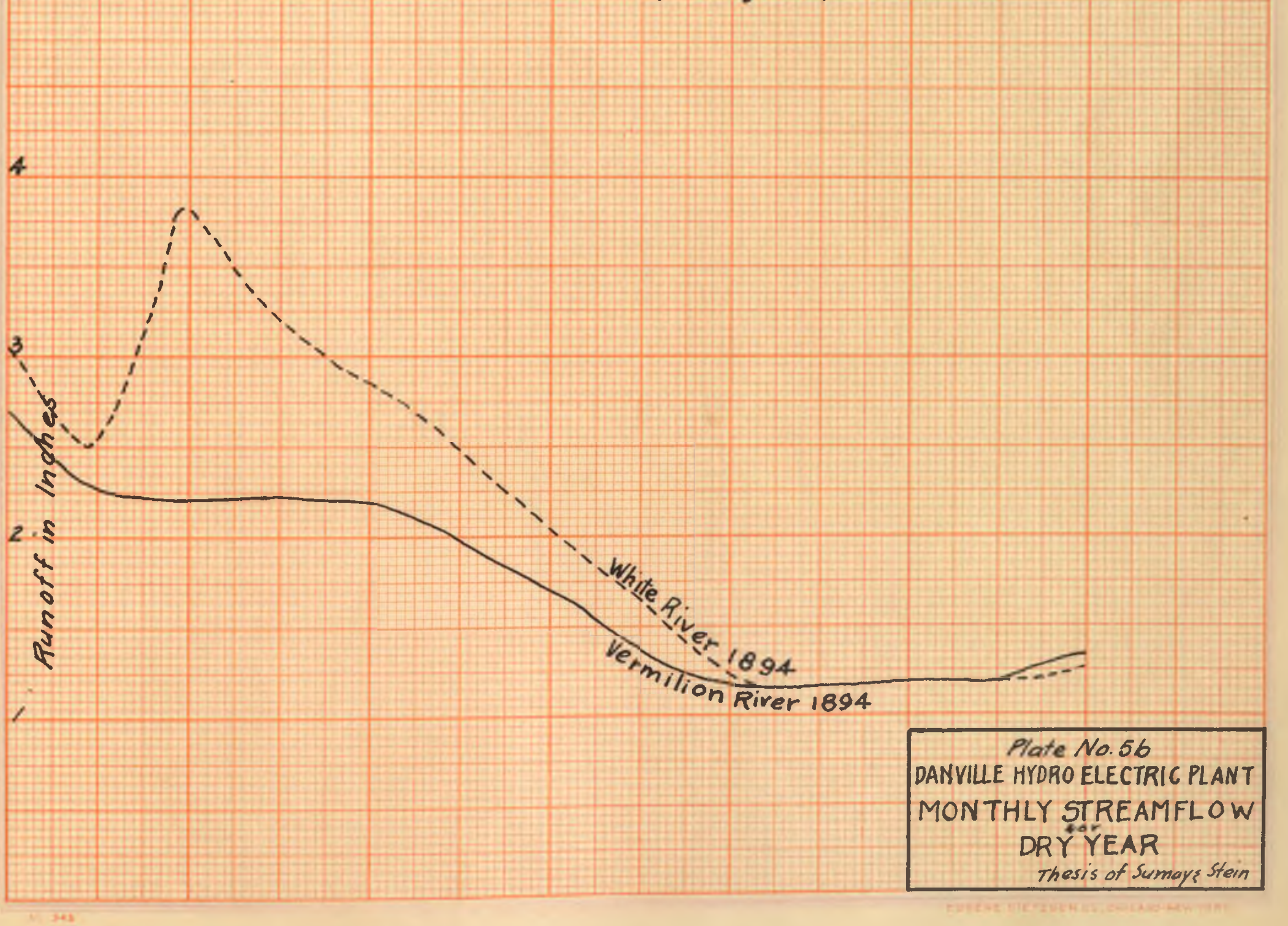


Plate No. 5b
DANVILLE HYDRO ELECTRIC PLANT
MONTHLY STREAMFLOW
for
DRY YEAR
Thesis of Sumay & Stein

TABLE 2
Minimum Flow - 1904

Stream	Location	Area	Daily Discharge July 20 - Dec. 20		Period & Amount of Least Discharge		
		Sq. M.	Max. Sec. Ft.	Min. Sec. Ft.	Date	Days	Discharge Sec. Ft.
Licking River	Pleasant Valley, O.	696	810	66	Nov. 27, - Dec. 5.	9	66
Olentangy "	Columbus, O.	520	104	5	Sept. 26, - Oct. 4.	9	5
Scioto "	" "	1051	215	7	Sept. 24, - Sept 26.	2	24
Wabash "	Logansport, Ind.	3163	1118	280	Oct. 18, - Nov. 13	26	350
Tippicanoe "	Delphi, Ind.	1890	1200	291	Aug. 7, - Aug. 16	10	335
White "	Shoales, Ind.	4900	1330	215	Oct. 22 - Dec. 23	63	360
White "	Indianapolis, Ind.	1520	712	62	Aug. 1, - Dec. 24	145	240

From an examination of the results it is evident that Vermeule's method gives a conservative estimate of the monthly flow, which follows the fluctuations of actual flow quite closely. Kuichling's method often departs widely from actual conditions, especially during the critical periods of minimum stream flow. Vermeule's method would therefore seem the best to be used in estimating the flow of the Vermilion and comparing it with that of other streams.

Plate 5a shows the monthly stream flow of the Vermilion river for a year of maximum precipitation, and Plate 5b shows the monthly stream flow for a year of minimum precipitation.

In regions having similar conditions of topography, geology and climate, stream flow has been shown to be closely correspondent. For this reason it is good engineering practice, in lieu of more exact data with regard to the regime of a certain stream, to assume its flow to be similar to that of an adjacent stream for which such exact data is obtainable. In the present instance there are several streams with which a comparison may be made. They are:

1. The Sangamon River at Decatur, Ill.: This river has its rise within a few miles of the Vermilion and flows thru a country entirely similar in geology, topography and culture. Furthermore, since the two streams lie in the same latitude similar climatical conditions should obtain. The stream flow record was obtained from discharge measurements and gaugings made by the United States Geological Survey. The record, however, extends only over a few months and can only be used in estimating the minumum flow.

2. The White River at Indianapolis, Ind.: This stream is a tributary of the Wabash, drains a country similar to that of the Vermilion and its flow should

agree quite closely with that of the latter. Records from the U. S. Geological Survey.

3. The Iowa River, at Iowa City, Ia.: This river lies in about the same latitude as the Vermilion and drains a similar country. At Iowa City it is dammed, and furnishes power and light to the buildings of the University of Iowa. Records from the U. S. Geological Survey.

4. The Tippecanoe River, at Delphi, Ind.: This stream is tributary to the Wabash. It lies north of the Vermilion and differs from it in having a lake as its source. This should render the stream flow more uniform. Records from the U. S. Geological Survey.

Plate 6 shows a graphical comparison of these streams. The left hand half of the page gives the principal data concerning the streams compared, while the right hand half gives the monthly rainfall and runoff for the years in which comparison is made; the first diagram showing these data in the order of their occurance, and the second in the order of their magnitude. In every case the dotted lines show the rainfall and runoff (computed) for the Vermilion, and the heavy lines that for other streams. Attention is called to the fact that the runoff for the Vermilion, which was computed, agrees quite closely with the actual runoff for the streams considered, as is shown when they are plotted in the order of their magnitudes. In each case those years are plotted which show the greatest similarity in annual rainfall and the seasonal distribution thereof. The close agreement in the case of the White River, when considered in conjunctionwith the similarity in topographic, geologic and other conditions seems to warrant a more extended comparison.

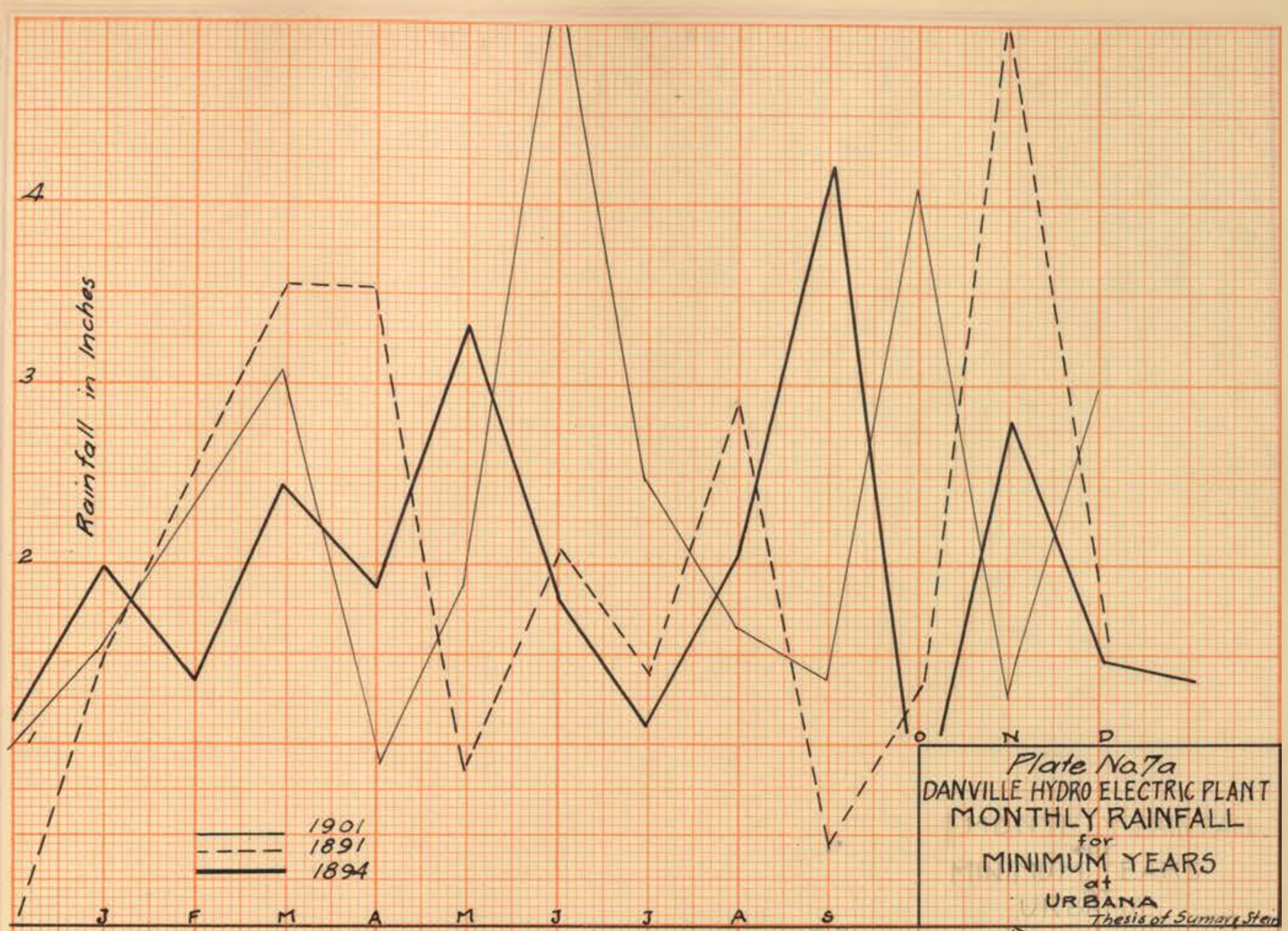


Plate No.7a
DANVILLE HYDRO ELECTRIC PLANT
MONTHLY RAINFALL
for
MINIMUM YEARS
at
URBANA
Thesis of Sumay & Stein
Rainfall in Inches
4
3
2
1
1901
1891
1894
J F M A M J J A S O N D

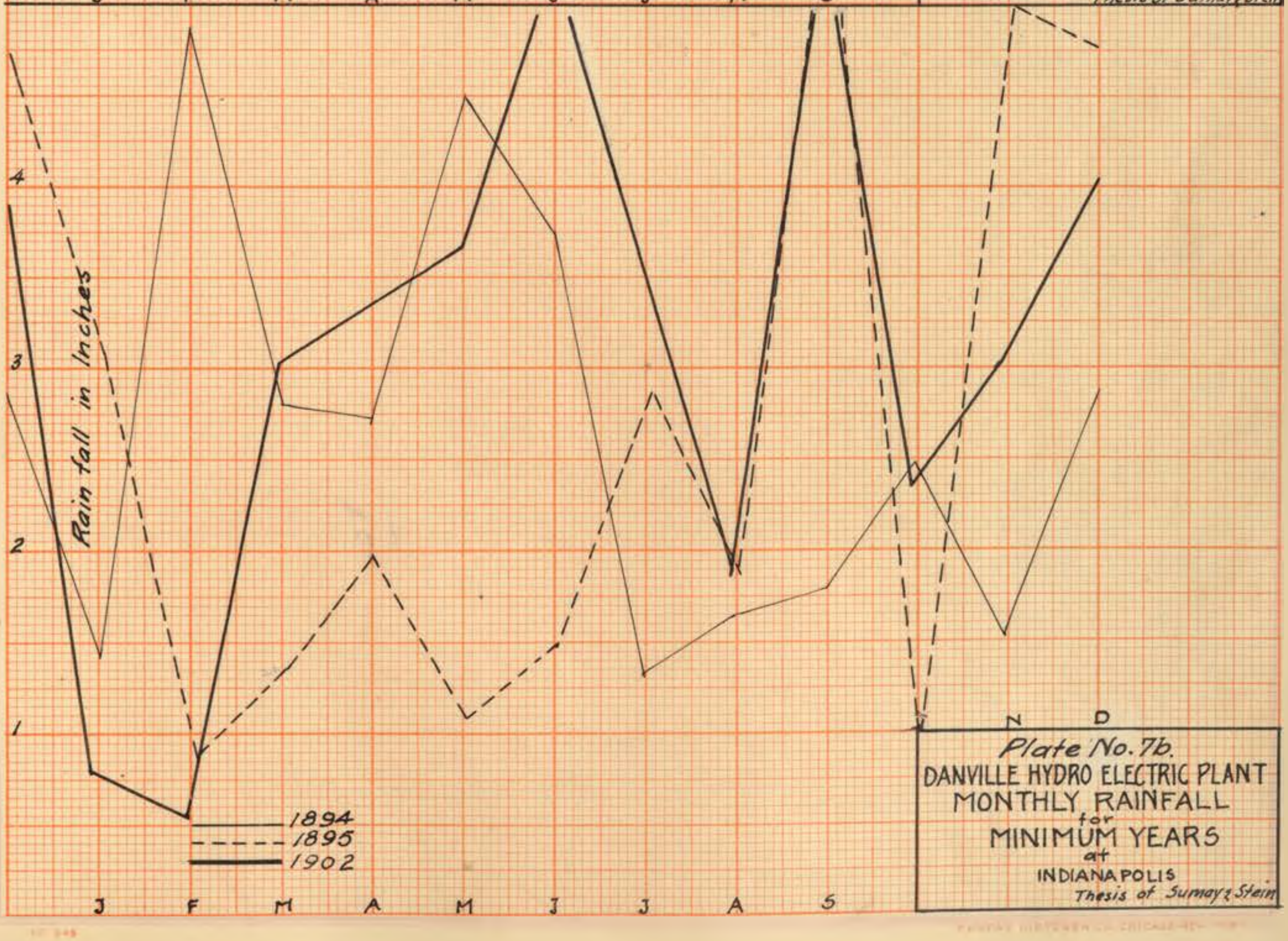


Plate No.7b.
DANVILLE HYDRO ELECTRIC PLANT
MONTHLY RAINFALL
for
MINIMUM YEARS
at
INDIANAPOLIS
Thesis of Sumay & Stein
Rain fall in Inches
4
3
2
1
1894
1895
1902
J F M A M J J A S O N D

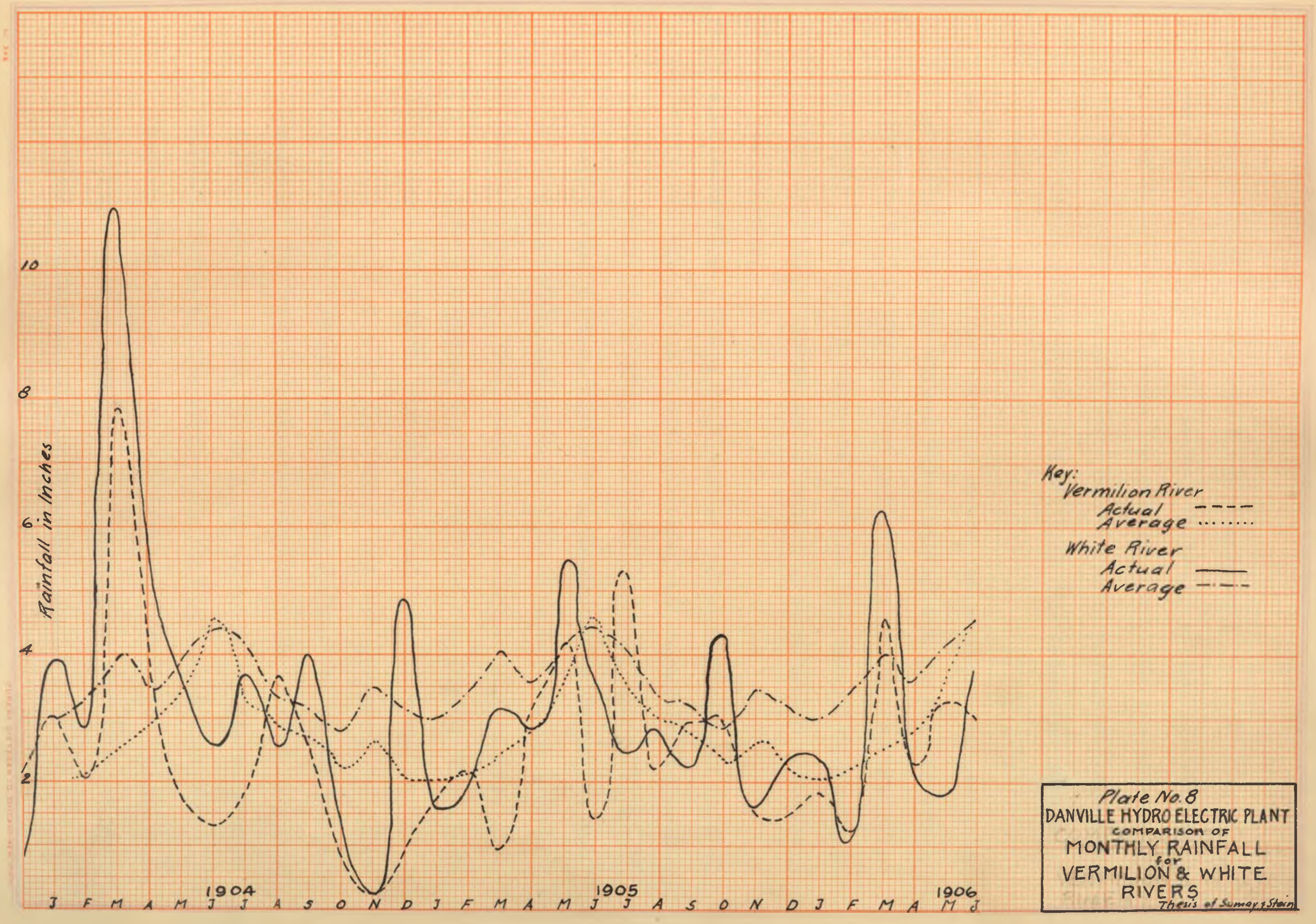


Plate No. 8
DANVILLE HYDRO ELECTRIC PLANT
COMPARISON OF
MONTHLY RAINFALL
for
VERMILION & WHITE
RIVERS
Thesis of Sumay & Stein

Comparison of White River and Vermilion River:

a. Annual Rainfall. The annual rainfall of the two valleys as shown on Plate 3 shows in general a similar periodic distribution. The rainfall for the Vermilion during minimum years is considerable lower than that of the White for similar periods.

b. Monthly Rainfall. Plate 7 shows the monthly variation in rainfall for the driest years during the period for which data is available. The maximum and minimum monthly rainfall is about the same in each case but in the case of Indianapolis the periods of large and of small precipitation are more extended .

c. Stream Flow. Plate 5a compares the monthly stream flow of the two rivers for a maximum year. The agreement between the two curves is striking. The Vermilion has somewhat the larger summer flow. Plate 5b compares the flow of the two rivers for a minimum year. The flow during the summer months, which is the critical period for minimum flow, agrees closely.

Plate 4 compares the flow of the two streams for a period of about two years. The stream flow of the Vermilion is always below that of the White, but the agreement is quite close during periods of low flow. Plate 8 shows the monthly rainfall and the mean monthly rainfall for each valley during the period for which Plate 4 shows the stream flow. From a consideration of the above data it would seem that the stream flow for a normal year for the Vermilion might well be represented by that of the White River for 1905, however, making a reduction of ten per cent. The flow of the White

River, should first be increased by 25 per cent of the extreme low water flow, as this amount is withdrawn above the gauging station for water supply purposes.

Minimum Flow: 1904 was a year of drought thru-out the valley of the Ohio River and may fairly be taken to represent extreme low water conditions in the Ohio River and streams tributary thereto. Data for the low water flow during this period of a number of streams was collected by the U. S. Geological Survey,*and is here reproduced. (see Table 2)

Daily gaugings for the White River at Indianapolis during this period are available and may be used to represent low water conditions on the Vermilion, being first increased by 25 per cent for the reason above mentioned.

Maximum Flow: The maximum flow of a stream may be obtained from past records of the maximum flood height, from comparison with neighboring streams, or from various rules and formulas. The maximum flood flow for the Vermilion River as obtained from a number of the more common formulas is shown in Table 3. Wherever possible the formulas were traced back to their source, in order to ascertain their applicability to the case in hand. They naturally fall into three classes; 1st. Those giving flood flows such as may be expected at frequent intervals; 2d. Those giving flood flows to be expected at long intervals; 3d. Those giving values obviously inapplicable in the present instance. In the table this classification is used. The formulas of Craig and Cooley agree closely in giving the normal flood flow as

* W. S. &.I. No. 127.

TABLE 3.
FLOOD FLOW BY FORMULAS

NAME	FORMULA	DERIVATION	APPLICIBILITY to DESPLAINES RIVER by JOHNSTON*	APPLICATION TO VERMILION						
				A	B	L	N	NORMAL FLOOD FLOW	DESTRUCTIVE FLOOD FLOW	EXCEPTIONAL FLOOD FLOW
				Sq. M.	Miles	Miles		Cu. Ft/Sec/M	Cu. Ft/Sec/M	Cu Ft/Sec/M
Dicken's	$Q = 825 A^{\frac{3}{4}}$	Measurements on East Indian Streams	Poor	1340						130
Dicken's	$Q = N \times 27 A^{\frac{1}{2}}$	" " " " "		1340			35		25.8	
Dredge's	$Q = 1300 A L^{-\frac{2}{3}}$	" " " " "	Poor	1340		67				79
Craig's	$Q = 440 BN \log_e \frac{8L^2}{B}$	Rational, but based on meagre data	Good		20	67	.33	16.4		
Cooley's	$Q = 180 A^{\frac{2}{3}}$	Based on normal high water of several streams of 5 to 110 sq.m., and checked on one of 1000 sq.m. area. All streams among low hills near St. Charles, Mo.	Good	1340				16.5		
Fanning's	$Q = 200 A^{\frac{5}{6}}$	Based on records available in 1889 mostly from New England	Poor	1340						61
Murphy's	$Q = \frac{46790}{A+320} + 15$	Applicible to Northeastern States		1340					43.2	
Chamier	Rational	Based on length of stream, slope, etc.				67			44.4	
Kuichling	Curve	For Occasional Floods							47.0	
"	"	For Rare Floods								80

* Proc. W. Soc. E., 1896, p 306

TABLE 4.
DESTRUCTIVE FLOODS

STREAM	DATE	METEOROLOGY: RAINFALL: DURATION Minutes	METEOROLOGY: RAINFALL: AMOUNT IN INCHES	METEOROLOGY: SNOW ON GROUND in In. of Rain	METEOROLOGY: TEMPERATURE AT TIME OF FLOOD	TOPOGRAPHY: LENGTH OF STREAM ABOVE POINT	TOPOGRAPHY: SLOPE Feet per Mile: AVERAGE for STREAM	TOPOGRAPHY: SLOPE: ABOVE POINT	TOPOGRAPHY: SLOPE: BELOW POINT	TOPOGRAPHY: SHAPE OF BASIN	TOPOGRAPHY: AREA ABOVE POINT	HYDROLOGY: VELOCITY Ft. per Sec.	HYDROLOGY: DISCHARGE Cu. Ft. per Sec. per Sq. Mile	REMARKS
Mohawk River	Mar. 22, '04		0.00	5.92	34	a. 45	2.3	2.3	2.3	Compact. 2 streams	1306			Flood due to rapid melting of
at Little Falls, N.Y.	" 23		0.71	----	38	b. 52				of equal size meet a-				snow. Rain above point Mar. 22d
	" 24		0.00	----	43					bove point: a. Mohawk				Not much damage done.
	" 25		0.35	----	43					River, b. West Canada				
	" 26		0.18	----	42					Creek.			20.8	
Grand River	Mar. 22, '04		0.43	March 6th, 20" at Lansing " 20, 1" " Grand Rapids Depth on Ground	42	130	1.8	3.3	0.8	Fairly Compact, flow	4940			Worst flood since 1887. Dams
at Grand Rapids,	— —	—	—		40 48					sluggish at Grand				and bridges destroyed.
Mich.	" 25		0.66		45					Rapids.				
	" 26		T		26									
	" 27		0.07		20									
	" 28		T		26								8.04	
Grand River,	Mar. 24 '04		0.84	Mar. 6, 20" snow on ground	46	a. 36	2.36	2.36	2.36	Compact. Two streams	1230			
at Lansing,	" 25		0.32		38	b. 50				unite above point: a.				
Mich.	" 26		0.04		21					Red Cedar River, b. Port-				
	" 27		T		20					age River. Strikingly				
	" 28		0.00		28					resembles Vermilion				
										above Danville.			18.7	See Grand River at Grand Rapids
White River,	Mar. 26 '04	345	1.92	—	.....	140				Fan shaped, many branches	4900	6.0	16.3	Largest flood since 1885; caused
at Shoales, Ind.	" 26 "													by two successive storm centers
														passing up valley. Very des-
White River	Mar. 26 '04	1140	4.72	—	.....	90				Rather long, spread-	1520			tructive. Damage to munici-
at Indianapolis	Mar. 26 '04									ing near head waters				pal works at Indianapolis,
														$170,000.
Wabash River, Logansport.	Jan. 29, '04										3163	6.95	14.8	

about 16 cubic feet per second per square mile. The formulas of Murphy, Chamier and Kuichling all give values ranging from 43 to 47 cubic feet per second per square mile as the maximum flow. Dicken's formula gives a value of 25.8 but is not to be relied upon owing to its origin.

Table 4 gives the flood records for a number of streams, most of these values being from Murphy's paper on " The Destructive Floods of 1904". The streams have been chosen with special reference to their topographical similarity to the Vermilion, wherever possible. Special attention is called to the Grand River at Lansing, Michigan. In drainage area, shape of valley, slope, and distribution of water courses it strikingly resembles the Vermilion. The flood of March, 1904, was caused by melting of a large amount of snow by a sudden rise in temperature assisted by a moderate rain. Great damage was caused by this flood, dams and bridges being washed out or destroyed. The floods in the valley of the Wabash during March 1904 were caused by two heavy rainstorms passing up the river in rapid succession. These floods were of a very destructive character. Gauge readings were taken at Indianapolis as shown on Plate 9a. The discharge values given are only approximate being derived from an extension of the rating table for normal flow. According to the records of the Chicago and Eastern Illinois Railroad, the highest water ever known on the Vermilion occured June 30th , 1902, when the water rose to within 7feet, 11.5 inches of the rail on their bridge, crossing the river below Danville. From a profile of this railroad we find the cross-sectional area of the river valley at this height below the base of rail of the bridge (= 7500 square feet). Assuming a mean velocity of four miles per hour (see Table 4 for values of flood velocity)

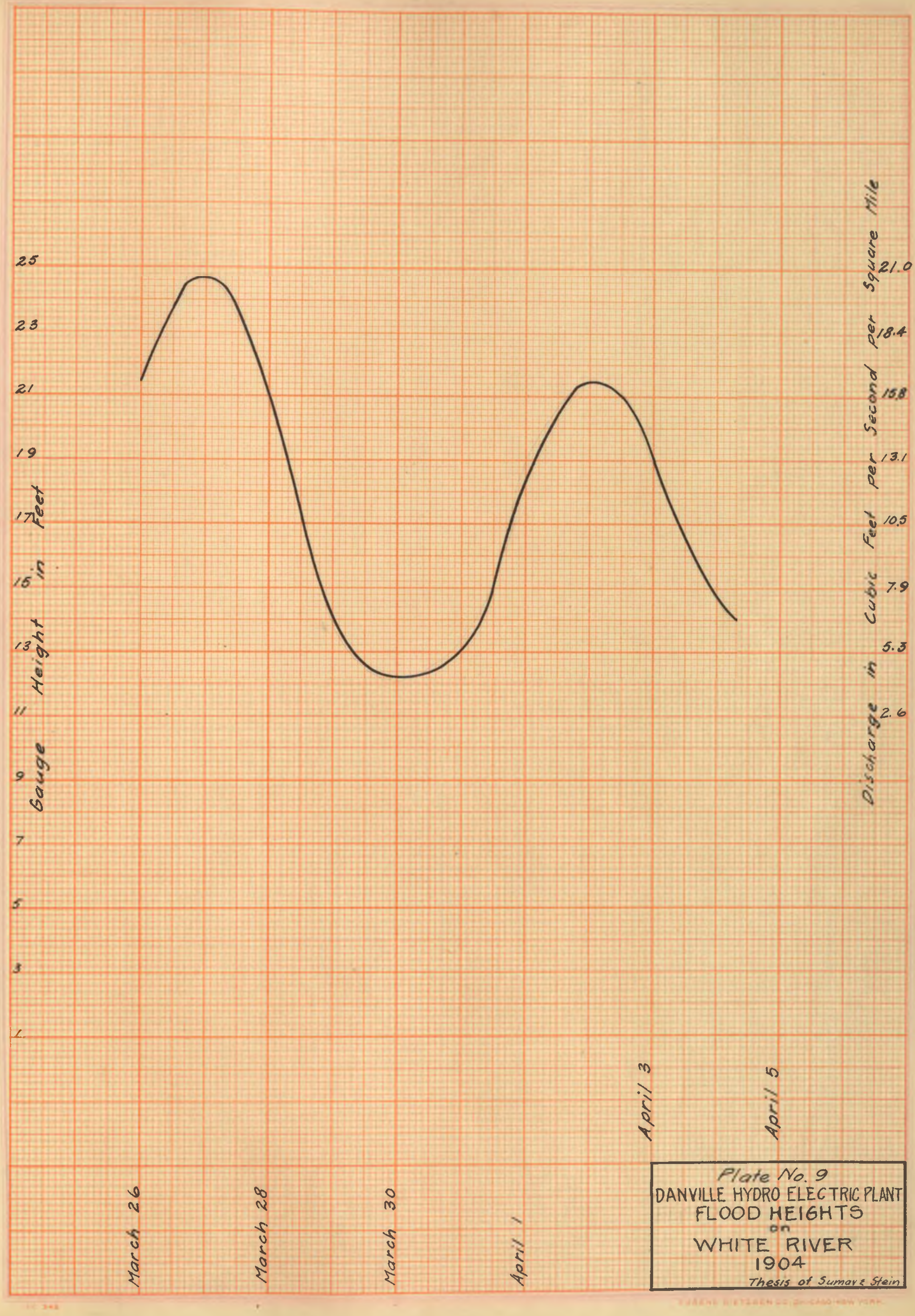


Plate No. 9
DANVILLE HYDRO ELECTRIC PLANT
FLOOD HEIGHTS
on
WHITE RIVER
1904
Thesis of Sumavz Stein

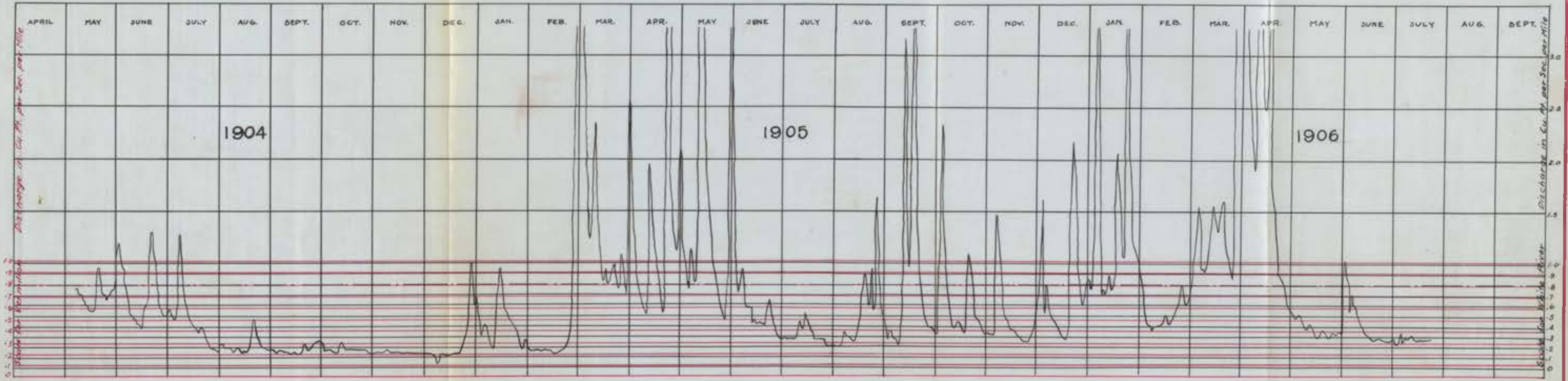


Plate No. 10.
DANVILLE HYDRO ELECTRIC PLANT
HYDROGRAPH
for
VERMILION RIVER
Thesis of Sumay & Stein

gives a discharge of 32.8 cubic feet per second per square mile.

We have measured a number of places along the river pointed out to us as having been reached by the greatest flood known and have found that their heights above low water level of the river agree closely with that recorded by the above railroad.

After a careful consideration of the above stream flow data we conclude that the following are conservative values for the Vermilion River and shall use them for the discussion and computation of water power in this report :

1. Daily variations for a normal year.

   The values to be used are those given for the White River at Indianapolis during 1905 by the U. S. Geological Survey increased by 25 per cent of the low water flow and decreased by 10 per cent . (see Plate 10)

2. Minimum Flow.

   The minimum flow and duration there-of are to be assumed as those given for the White River from July to December, 1904, by the U.S. Geological Survey, increased by 25 per cent and decreased by 10 per cent as above.

3. Maximum Flow.

   a. The maximum flow to be expected every year is to be assumed as 15 cubic feet per second per square mile and its duration as 6 days.

   b. The maximum flood to be expected occasionally is to be assumed as 30 cubic feet per second per square mile.

FALL OF THE RIVER: Table 5, page 14, shows the fall per mile for different stretches of the Vermilion River above and below Danville. This shows that the fall is greatest for a

TABLE 5.

STATION	LOCATION	DISTANCE BETWEEN STATIONS	ELEVATION	FALL PER MILE	HORSE POWER DEVELOPED PER 10 FEET HEAD			
					WITH TOTAL DISCHARGE		ALLOWING FOR FLOODS	
					THEORETICAL	75% EFFICIENCY	THEORETICAL	75% EFFICIENCY
		Miles	Feet					
1	Above mouth of Coal Branch	0.0	490.0		1211	908	850	637
2	1 Mile S.E. of Grape Creek	5.6	500.0	1.8	"	"	"	"
3	At C.& E.I.R.R. Bridge	3.8	506.0	1.6	"	"	"	"
4	South of Danville	1.3	510.0	3.1	"	"	"	"
5	½ mile above mouth of North Fork	2.1	515.0	2.5	990	743	694	520
6	3 miles west of Danville	4.0	520.0	2.5	"	"	"	"
7	Above mouth of Middle Fork	4.5	530.0	2.2				
8	1½ miles above mouth of Middle Fork	1.5	540.0	6.7				

stretch beginning about three miles below Danville and extending to Station 8 and probably beyond . The average fall per mile for the total distance is 2.85 feet per mile, giving a fall of about 36 feet.

AVAILABLE POWER: The available power of a stream is a function of the discharge and the head. Knowing these quantities it may be found from the equation :

$$\text{Available Power} = \frac{\text{Head in ft.} \times \text{Discharge in cu. ft./sec.} \times 62.5}{550}$$

Values of available power for different points on the Vermilion are given in Table 5. This table gives the theoretical horse power with a head of 10 feet using:1st., the total annual flow of the stream; 2d., making a reduction of 30 per cent for loss due to excessive floods. The column head 75 per cent efficiency gives the actual horse power delivered by the turbines and available for power purposes or for conversion into electrical energy. Utilizing the 12 miles of greatest fall in the immediate vicinity of Danville gives a theoretical horse power of 4030, or 2110 actual turbine horse power if an allowance of 30 per cent be made for floods and the efficiency of the turbines be taken as 75 per cent.

DISPOSAL OF POWER: Since the power may be obtained in such close proximity to Danville this should be the natural market for the same. Danville is an uptodate and enterprising city of 40000 inhabitants. It is located in the center of a fertile farming country and near the north-eastern edge of the Illinois - Indiana coal - fields, there being many productive mines in its vicinity . It is also a railroad center, seven lines meeting at this point. Electricity for lighting and power purposes is at present supplied by a large steam plant operated and controlled by the

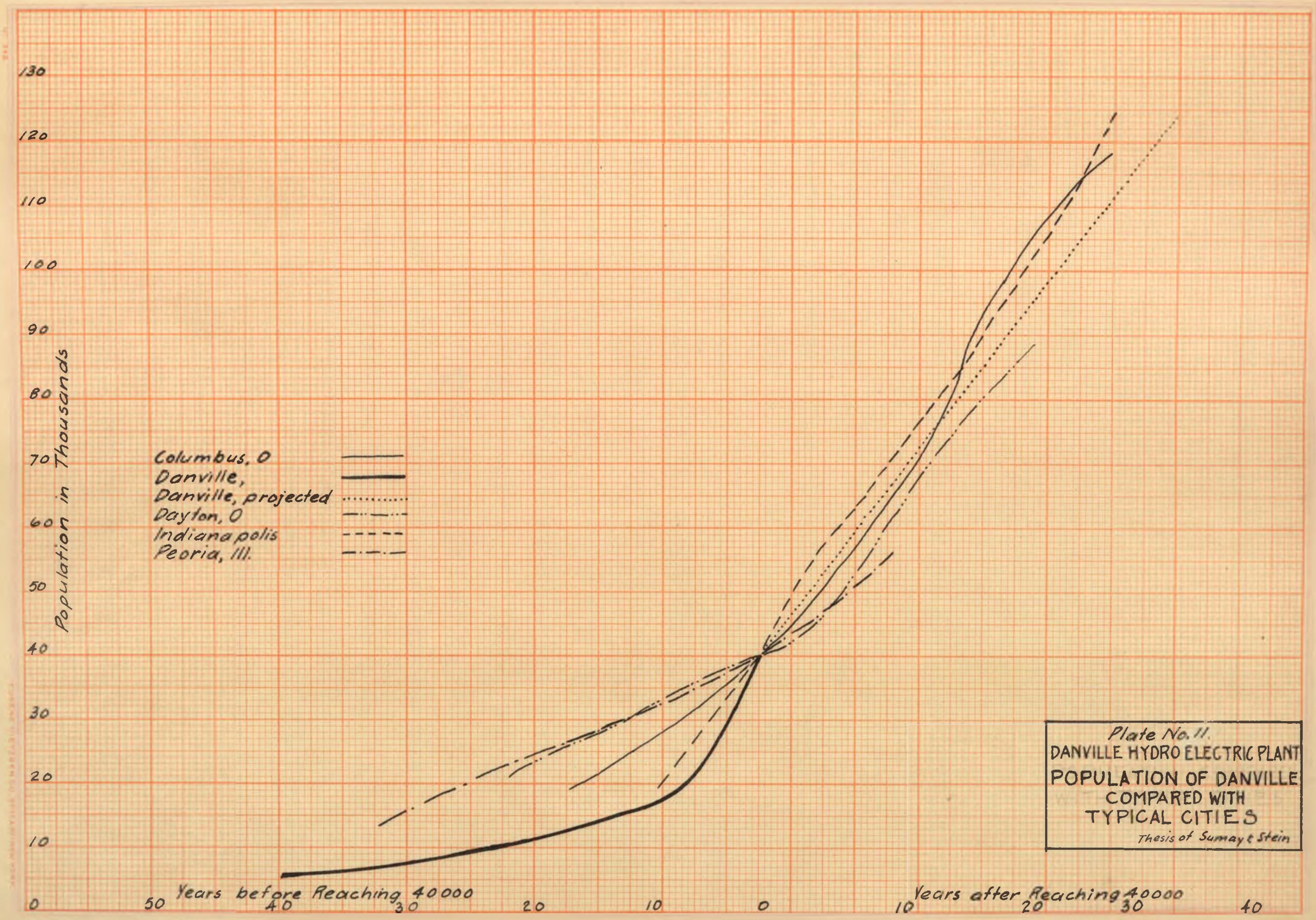


Plate No. 11.
DANVILLE HYDRO ELECTRIC PLANT
POPULATION OF DANVILLE
COMPARED WITH
TYPICAL CITIES
Thesis of Sumay & Stein
Population in Thousands
Years before Reaching 40000
Years after Reaching 40000
Columbus, O
Danville,
Danville, projected
Dayton, O
Indianapolis
Peoria, Ill.
0
10
20
30
40
50
60
70
80
90
100
110
120
130

Illinois Traction System. The output of this plant for the year 1908 was as follows:

For Lighting	4 800 000	Kilowatt hours
For Commercial power	120 000	" "
For Interurban power	7 200 000	" "
For City Railway power	1 200 000	" "
Total Output	13 320 000	" "

The safest basis for computing future increase in power is to assume that the present plant is to continue to operate at its present capacity and that the proposed plant is to provide for the future increase in power. Since hydraulic power is almost invariably cheaper than steam power, the proposed plant should be able to compete successfully for the future increase with the present plant. The probable increase in power demand will now be considered:

a. Lighting: The present per capita consumption for lighting purposes is 120 Kilowatt hours per year. Plate 11 shows the increase of population in Danville from 1870 to date and its probable future growth based on the growth of other cities after they had reached the present population of Danville. From this it will be seen that at the present rate of consumption additional power to the extent of 1 800 000 Kilowatt-hours per year will be required to supply the lighting in ten years. This does not take account of the increase due to the more extensive use of electric lighting or of the effect of a reduction of rates.

b. Commercial use: At present little use is made of electricity for power purposes. Danville has manufacturing facilities and it is probable that manufactures will greatly increase.

TABLE 6.
CENSUS OF POWER USERS IN DANVILLE

FIRMS WRITTEN TO	POWER USED		AGE of PRESENT PLANT	NATURE OF WORK	WOULD YOU BE WILLING TO CHANGE FROM PRESENT TO ELECTRIC POWER IF IT COULD BE SUPPLIED MORE CHEAPLY ?
	KIND	AMOUNT H.P.			
C. & E. I. R.R. Shops	Steam	1200	5 years	Locomotive Repairs	
Danville Car Co.	Electric	Not given	1½ "	Car Building	"Would not say. Using central station power."
Danville Ice Co.	Steam	200	10 "	Artificial Ice	"Yes, except for steam used in distillation"
Hegeler Bros.	Steam-Electric	670	Not given	Zinc Smelters.	Present installation sufficient.
Fecher Brewing Co.					Personal consultation asked.
Western Brick Co.	Steam	1000	8 years	Brick	"Would consider it."
Danville Brick Co.	Steam	300	2 "	Brick	"Sure"
Danville Foundry & Machine Co.					
Robt. Holmes & Bros.	Steam	35	8 "	Machine Shop.	"Yes."
Headley Glass Co.	Steam	200	6 "	Glass Works	"Need some steam for producing gas.
Chesley Bros.					
Eureka Planing Mill					
Riverside " "	Steam	60	3 "	Wood Work	Personal consultation asked.
Stahl-Urban Co.					
Central Soap Co.					
Already Box Co.					
Ryan Carriage Co.					

Between the years 1905 the manufactures of Danville increased as follows:

Item	1900	1905	Increase
Capital invested	$ 1 413 057	$ 2 102 062	48.8 %
No. of wage earners	957	1 884	96.9 %
Cost of materials used	$ 1 047 310	$ 1 665 380	59.0 %
Value of products	$ 1 913 762	$ 3 304 120	72.7 %

In order to obtain an opinion as to the attitude of the principal manufactures regarding the use of electric power a partial census of power users was taken with the results shown in Table 6.

From an examination of this table the following summary is derived:

Total power used by principal factories	3 670 H.P.
Power furnished by plants over eight years old	1 235 H.P.
Power used by manufacturers who would probably change	1 500 H.P.

As an additional market for commercial power the town of Hoopston may be mentioned. This town is located about 25 miles north of Danville and contains a number of large canneries and other factories, as listed below:

American Can Co.	April to October	145 H. P.
	October to March	75 H. P.
Illinois Canning Co.	July to November	150 H. P.
	November to June	50 H. P.
Hoopeston Canning Co.	July to November	150 H. P.
	November to June	50 H. P.
Hoopeston Horse Nail Co.	Night and day	100 H. P.
Sprague Mfg. Co.		100 H. P.
Hoopeston Malleable Iron Co.		60 H. P.

Municipal plant	160 H. P.
Machine shops	50 H. P.
Total	1120 H. P.

In estimating the possibilities of Danville as a market for commercial power it must be remembered that the manufactures are growing very rapidly, having increased over 50 per cent during the last five years; and also that cheap power would still further stimulate this growth. In this connection attention is called to the towns of Sterling and Rock-Falls, Illinois, which contain factories aggregating 4000 horse power capacity, and owe their prominence as manufacturing centers entirely to the presence of a water development on the Rock River.

The probable use of power by small consumers should be considered . As power rates become reduced, an increasingly larger amount of power will be used by the shopkeeper and tradesman:

c. Transportation: Data as to the past increase in power used for urban and interurban transportation could not be obtained. However, as the city increases in size, the street railway traffic and mileage will also increase. This possible method of power disposal had best be regarded as an additional factor of safety in the financial success of the plant.

The conditions of Danville and the vicinity as a market for power may be summarized as follows:

Probable power which could be sold now:

a. Lighting:	500 000	KW. hours
b. Commercial:	7 200 000	" "
c. Miscellaneous:	200 000	" "
Total	7 900 000	" "

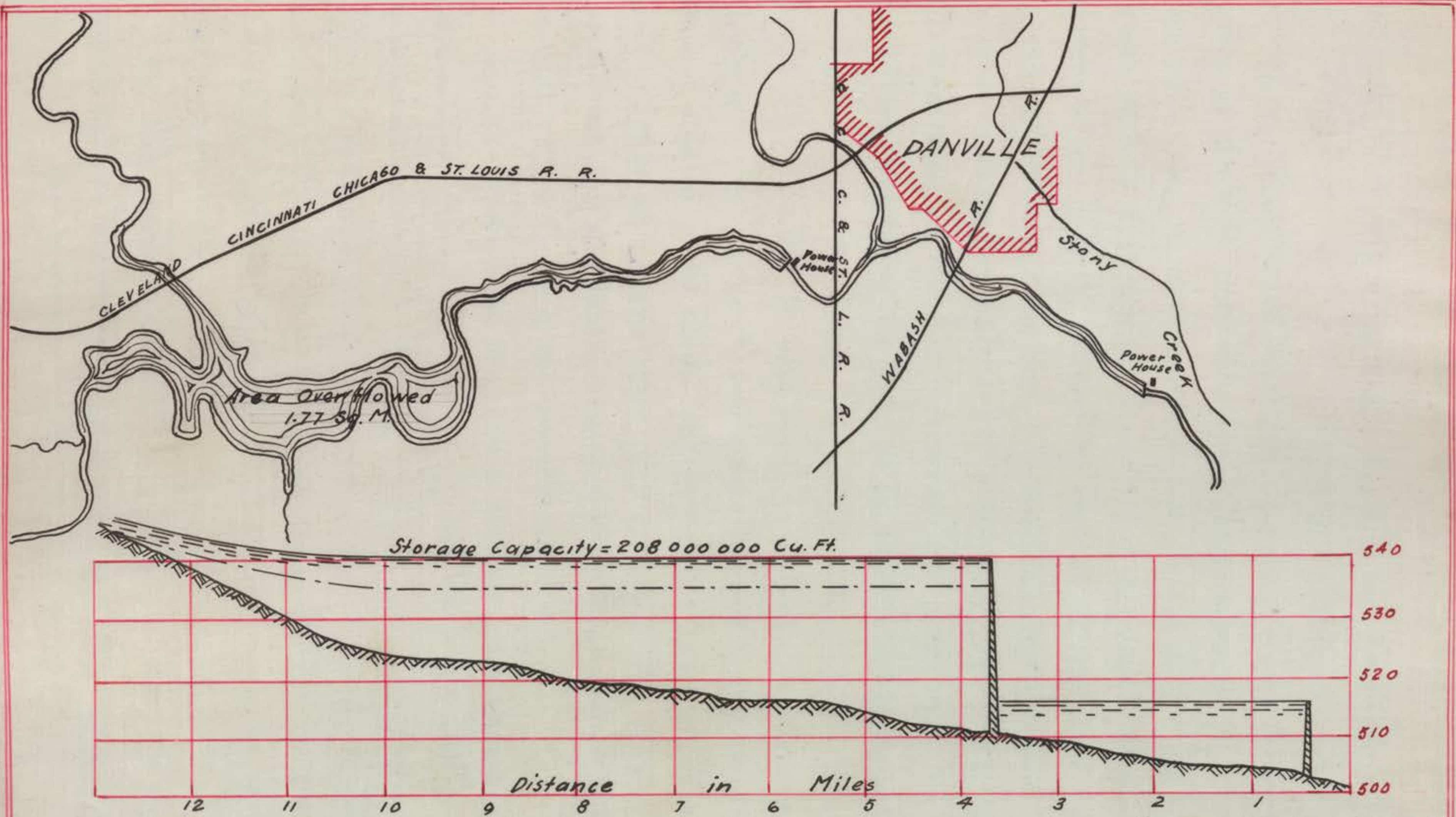


Plate No. 12

DANVILLE HYDRO ELECTRIC PLANT

PROPOSED PLAN of DEVELOPMENT

Thesis of Sumey & Stein.

PROPOSED PLAN OF DEVELOPMENT: After a careful study of the topographic and geologic conditions of the Vermilion River, based on extensive personal reconnoissance and a study of the best available topographic maps, we have decided that the best plan of development is that shown in Plate 12. This consists of a 25 foot dam built about one and a half miles above Danville across a very narrow, gorge-like portion of the river valley. Such a dam will create a pondage of 1130 acres with an available storage capacity of 208 000 000 cubic feet, which will be valuable in equalizing the flow of the river. The power house is to be built as a continuation of the dam, it is to have a capacity of 1500 continous H. P. and is to be provided with an auxiliary plant of sufficient capacity to take care of the load on the plant during periods of low water. It is further suggested that at some future date a similar power plant, operating on a ten foot head, be constructed about 3.5 miles below Danville, near the present bridge of the Chicago and Eastern Illinois Railroad. At this plant the storage of the upper plant would be available.

For the purpose of discussing the best development program, use of auxiliary power, storage, etc., the daily and monthly load of a typical Central State station, operated under conditions similar to those obtaining at Danville are shown on Plates 13 and 14. To illustrate the method of procedure the case based on the assumption that an average yearly output of 1500 H. P. is to be maintained will be explained.

For this purpose the monthly power curve Plate 14 must be adjusted so that the average monthly power line represents.

$$1500 \times 30 \times 24 = 1\ 080\ 000 \text{ H. P. hours}$$

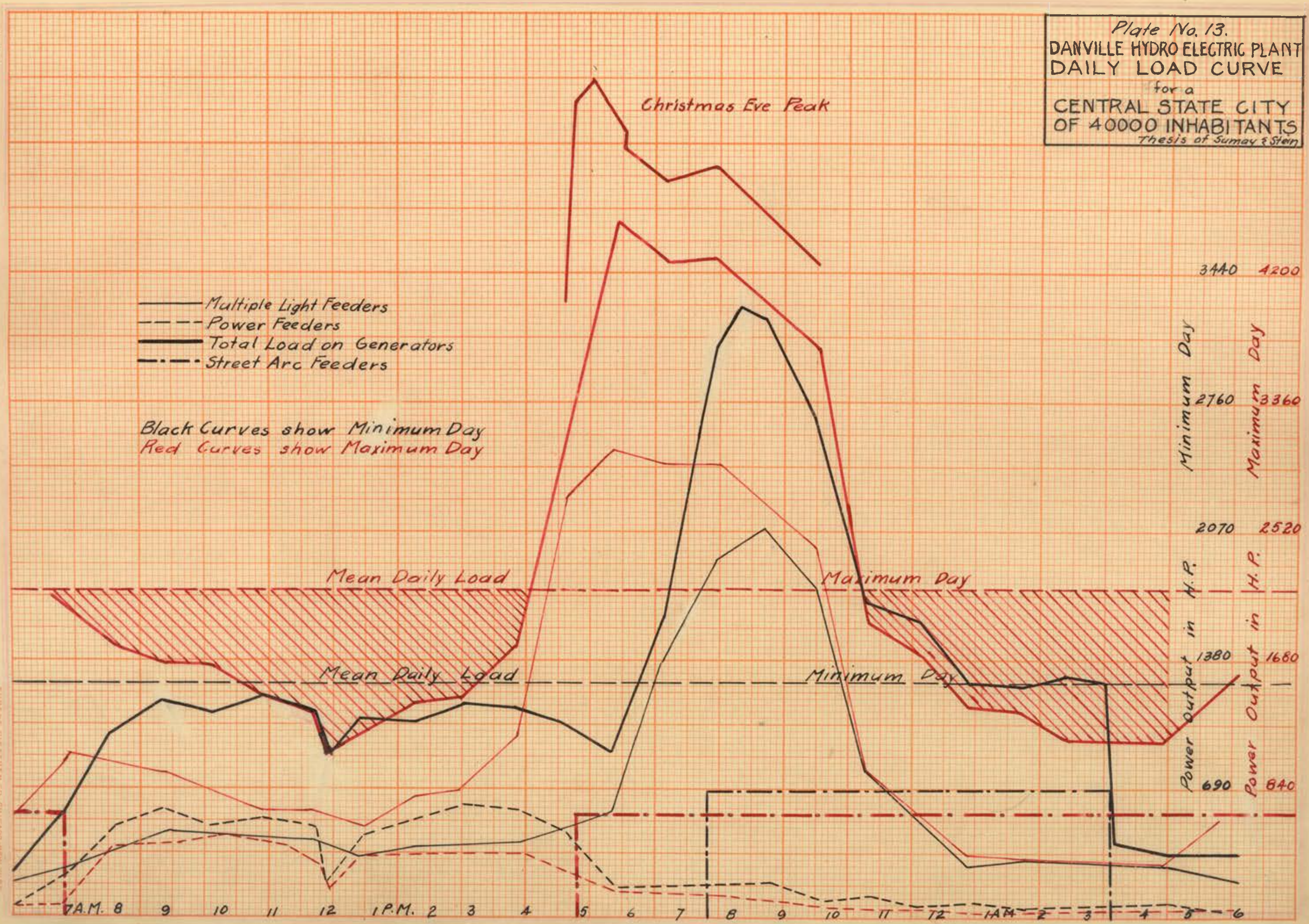


Plate No. 13.
DANVILLE HYDRO ELECTRIC PLANT
DAILY LOAD CURVE
for a
CENTRAL STATE CITY
OF 40000 INHABITANTS
Thesis of Sumay & Stein
Christmas Eve Peak
Multiple Light Feeders
Power Feeders
Total Load on Generators
Street Arc Feeders
Black Curves show Minimum Day
Red Curves show Maximum Day
Mean Daily Load
Maximum Day
Mean Daily Load
Minimum Day
Minimum Day
Power Output in H.P.
Maximum Day
Power Output in H.P.
3440
2760
2070
1380
690
4200
3360
2520
1680
840
7 A.M. 8
9
10
11
12
1 P.M.
2
3
4
5
6
7
8
9
10
11
12
1 AM
2
3
4
5
6

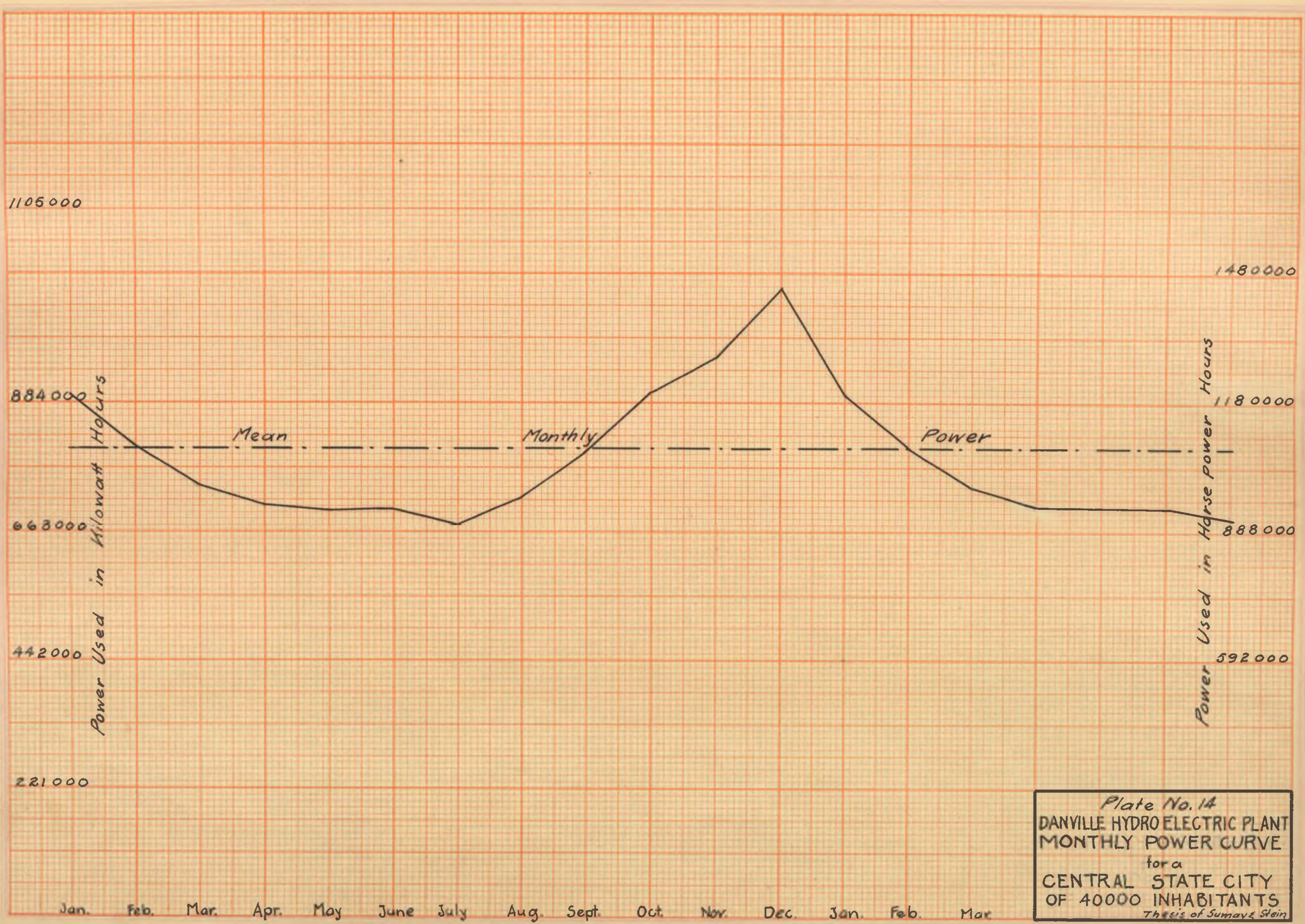


Plate No. 14
DANVILLE HYDRO ELECTRIC PLANT
MONTHLY POWER CURVE
for a
CENTRAL STATE CITY
OF 40000 INHABITANTS
Thesis of Sumaye Stein

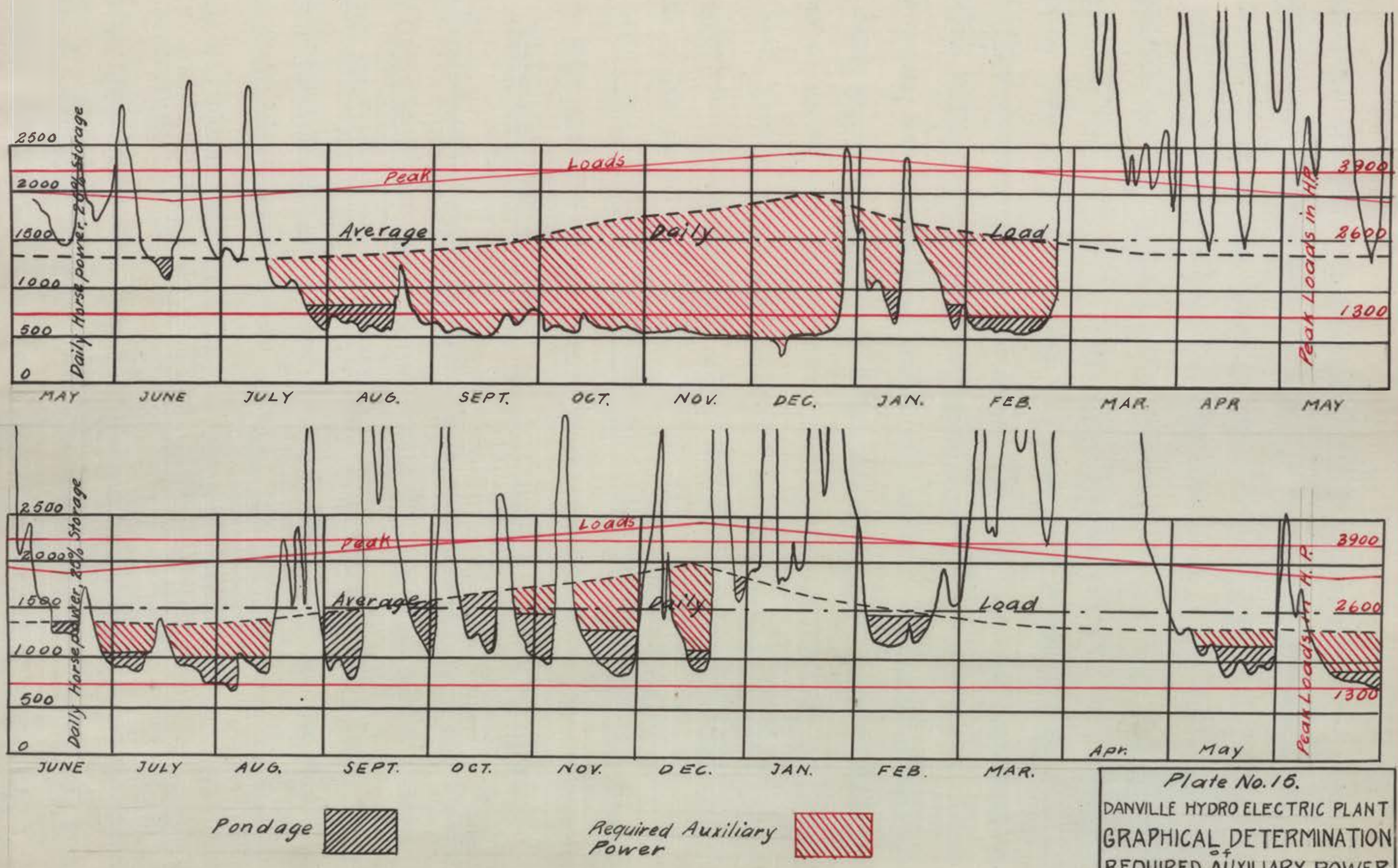


Plate No. 15.

DANVILLE HYDRO ELECTRIC PLANT

GRAPHICAL DETERMINATION of REQUIRED AUXILIARY POWER

Thesis of Sumay & Stein

It will be seen that the maximum monthly output for December is 1 440 000 H. P. hour and the average daily for maximum month is 50 000 H. P. hour. The average line on the daily load curve, Plate 13 may now be fixed as 50 000 / 24 or 2080 H. P., and the scale of the ordinates may be adjusted to correspond. This places the peak load at 4200 H. P.. The daily load curve brings out the fact that the load is less than the average for most of the day and considerably above the average during the peak. This load may be equalized by storing water during times of small load to be used during times of peak load. The shaded area shows the quantity of water power which may thus be saved. By integrating the respective areas this is found to be 24 per cent of the total average power. By similar methods the peak load for the minimum month is found to be 3180 H. P., and the increase in water horse power which may be effected by pondage is 26.4 per cent.

The hydrograph, Plate 10, is now redrawn to a scale such that one cubic foot per second of runoff corresponds to

$$\frac{1 \times 1050 \times 62.5 \times 22.5}{550} \times .75 \times .95 \times 1.25 = 2500 \text{ H. P.}$$

which represents the electrical horse power available at the switch board of the power house for a stream flow of one cubic foot per second per square mile with 75 per cent turbine efficiency, 95 per cent generator efficiency and the necessary pondage. On this revised hydrograph the monthly power curve is plotted as shown by the dotted line. The deficiency between the average required horse power and the actual available water horse power is made up, 1st., by filling in with water from the storage reservoir as far as possible (see black cross-lined portion); 2d., by filling in the remainder with auxiliary power (see red cross-lined portion). Evidently the areas under the curve represent quantities of power. In this case the quantities found are as follows:

Normal Year, 1905:

Total water power	11 085 000 H. P. hours.
Total auxiliary power	2 015 000 H. P. hours.

Period of Drought, September to December, 1904.

Total water power	1 700 000 H. P. hours.
Total auxiliary power	3 310 000 H. P. hours.

The peak load is treated as follows: The peak load is about 176 per cent of the average and if the water power be considered as doing its proportional share of the work it will contribute 176 per cent of its average power toward the peak. The scale on the right hand side of the diagram is drawn to represent this condition. The red line above the diagram represents the peak load for various times of the year drawn to the same scale. The intercept between the water power line and the peak line represents the amount of auxiliary power required during the peak load. In this case the quantities are as follows:

Normal Year, 1905:

Maximum Peaks	Auxiliary power	2500 H. P.
	Water power	4000 H. P.
Minimum Peaks	Auxiliary power	00 and 800 H. P.
	Water power	1200 H. P.

A peculiar point is brought out by this hydrograph, namely; during the period of drought the maximum peak as scaled from the diagram is 3500 H. P., but calculation shows that the total water power for one day during this period is just sufficient to fill in the peak load, therefore if auxiliary power be used during the day, and all the water be stored for use during the peak,it will be unnecessary to have such a large auxiliary plant, which will be a large saving in first cost as such droughts occur only at comparatively rare intervals.

ESTIMATES: Table 7 gives an estimate of the plant and cost of operation. Depreciation is figured by means of the formula

$$D = \frac{C\,r}{(1 + r)^n - 1}$$

where: D = annual depreciation

C = first cost

n = life of structure in years

r = rate of interest.

An allowance is made for the value of machines as scrap.

The estimates, based on conservative values, show that the plant should earn an income of at least 7.25 per cent on the investment.

TABLE 7.
ESTIMATES.

UNIT PRICES USED:

Cement, Portland, per bbl., delivered		$ 1.50
Concrete, plain, 1-3-6, placed, per cu. yd		4.00
" " " formed and placed		5.50
" " 1-2-4 " " "		7.00
Reinforcing steel, placed, per lb.		0.035
Gravel, per cu. yd.		0.75
Lumber, per 1000 feet, B. M.		30.00
Labor, per day		1.75
Excavation, shale, per cu. yd.		
Plowing	$ 0.05	
Loading, hauling and dumping	0.19	0.24
Filling, per cu. yd.		0.20
Structural Steel, erected, per ton		100.00
Team and driver, per day,		3.75

I. FIRST COST:

Note: Unless otherwise stated, quotations are for materials in place, including labor, etc.

Land, 1130 A. @ $50 per A.	$ 56,600.00	$ 56,600.00

Cofferdams	$500.00	
Clearing and stripping	100.00	$600.00
Excavation, shale, 1000 cu.yd.	240.00	240.00
Spillway, 30 ft. high, 80 ft. long:		
288 cu. yd. 1-2-4 concrete,	2020.00	
32000 lb. steel,	1120.00	3140.00
Abutments, (2), 1000 cu. yd. 1-36 concrete	4000.00	4000.00
Earth embankment with concrete core, 150 ft. 37'h., 70 ft. 25'h., 75 ft. 18'h., 50 ft. 10'h.		
Corewall, 96 cu. yd. 1-3-6 concrete,	384.00	
Earth Fill, 934 cu. yd.,	187.00	571.00
Tainter Gates:		
2037 cu. yd. 1-3-6 concrete,	8118.00	
4 steel gates, @ $250 each,	1000.00	9118.00
Power House:		
6970 cu. yd. 1-3-6 concrete. @ $5.50,	38 384.00	
Trusses, 70 ft. span, 4 @ $122 each,	488.00	
Purlins, 20000 lb. @ $.025,	500.00	
Roofing, slate on wood sheathing, 100 sq. @ $9	900.00	
Windows, 1680 sq. ft. @ $0.25	420.00	
Fittings,	500.00	41,192.00
Power House Equipment		
Traveling Crane, 15 Ton	3000.00	
4-48 in. turbines with draft tubes @ $6 per H.P., 1106 H.P.	25,200.00	
2-15 in. turbines, 110 H.P. @ $6 per H.P	1320.00	

6 governors, @ \$300 each	\$1800.00	
Electric equipment:		
Generators, 3140 K.W. @ \$12 per K.W.	37,700.00	
Exciters, 157.5 K.W. @ \$12 per K.W.	1890.00	
Switch board, 3140 K.W. @ \$5 per K.W.	15,700.00	
Steam equipment:		
Engines, compound, highspeed, 3160		
H.P. @ \$21 per H.P.	59400.00	
Boilers, 3000 H.P. @ \$12 per H.P.	36000.00	
Heaters and Pumps	4700.00	
Piping	2800.00	
Draft:		
1- 10 ft. fan, \$900		
1- 30 H.P. Engine \$500	1400.00	184,810.00
Boiler House:		
Concrete, 1-3-6, 888 cu.yd @ \$5.50	4340.00	
Trusses, 12 - 45 ft. span, @ \$50 each	600.00	
Purlins, 22800 lb. @ 2½¢ each	570.00	
Roof, 114 squares @ \$9 per square	1025.00	
Track over Coal Bin.		
20 in. 65 lb. I's @ \$0.025, 30,800 lb.	770.00	
370 lin. ft. of 10"x12" stringers, @ \$.25	92.50	
123 yds. of 30 lb. rails @ \$1.00 per yd.	123.00	
Covers, 2850 ft. B.M. @ \$30	85.50	7706.00

Transmission Line: 1½ miles, 6600 volts,
3140 K.W, 7% drop, No. 0 wire,

Machinery:

Dynamos	$ 731.00	per year
Engines	1525.00	" "
Turbines	1390.00	" "
Boilers	938.00	" "
Auxiliaries	765.00	" "
Transmission Line	132.00	" "
Total Annual Depreciation	$6014.00	

V. COST OF OPERATION:

a. Generators and Turbines:

2 Operators @ $90 per month each	$.000167	per H.P. hour.
2 Assistants @ $60 per month	.000111	" " " "
1 Lineman @ $75 per month	.000070	" " " "
Repairs, Oil, etc., $1 per H.P. per year	.000275	" " " "
Office Expenses, Taxes, etc., $.50 per H.P. per year	.000130	" " " "
Total Cost per H.P. hour	$.000753	

b. Auxiliary plant:

Engineer's and Firemen's Wages	$ .000900	per H.P. hour
Repairs, Oil, etc.,	.000275	" " "
Fuel @ $0.75 per Ton	.001130	" " "
Office Expenses, Taxes, etc.	.000130	" " "
Total Cost per H.P. hour	$.002435	

VI. YEARLY POWER OUTPUT:

Water Power,	11,085,000 H.P. hours
Steam Power,	2,015,000 H.P. hours

53 poles, set @ $3.00 each	$212.00	
Insulators, 159 @ $.50 each	80.00	
Pins, 159 @ $.25 each	40.00	
Wire, No. 0, 7620 lb, @ $.15 per lb.	1142.00	
Stringing wire @ $15 per mile	22.50	
Wooden towers, 4 @ $20 each	80.00	
Cable, $\frac{1}{4}$ in. steel, @ $0.01 per ft. 800 ft.	8.00	1584.50
First Total		$309,561.50
Engineering and inspection, 5 per cent		15,450.00
Grand Total		$325,011.50

II. COST PER KILOWATT:

Power generated	3140 K.W.
Cost per K.W, generated	$103.25

III. LIFE OF PLANT:

Dam, Buildings and Concrete Work: 50 years

Machinery:

Dynamos,	30 years,	residual value	8%
Engines,	25 years,	" "	6%
Turbines,	15 years	" "	2%
Boilers,	25 years	" "	5%
Auxiliary machinery	25 years	" "	5%
Transmission line	10 years	" "	5%

IV. DEPRECIATION:

Interest at 3%

Dam, etc., $543.00 per year

DESCRIPTION OF PLANT.

LOCATION: The site chosen for the location of the plant is about 2000 feet above the bridge-crossing of the C. C. C. and St. L. Railroad and about two and one half miles from the court-house square. The river valley at this point narrows considerably, there being a steep bluff of over one hundred feet high on the west side of the stream, which here flows in a south-easterly direction, while the east side rises in a series of terraces, ultimately reaching a height of eighty feet above the bed of the stream. Soundings made along the bed and banks of the stream at this point show a stratum of shale at a depth of about three feet below the river bottom. While these soundings in themselves are inadequate for determining the nature of foundation for such important structures as a dam and power house, their results are fully confirmed by the C. C. C. and St. L. Railroad prior to the construction of the large concrete arch bridge which crosses the stream near this point, and the examination of several shale pits dug in this vicinity. This shale stratum affers a very desirable foundation especially if protected to some extent from scour. The material above the shale is composed largely of gravel and sand, merging gradually into the glacial drift typical of this region as we recede from the banks of the stream. The water as backed up by the proposed dam, will overflow some of the bottom land, part of which is in a state of semi-cultivation, but which is subject to inundation during even moderate floods, as has been determined by personal observation. This land

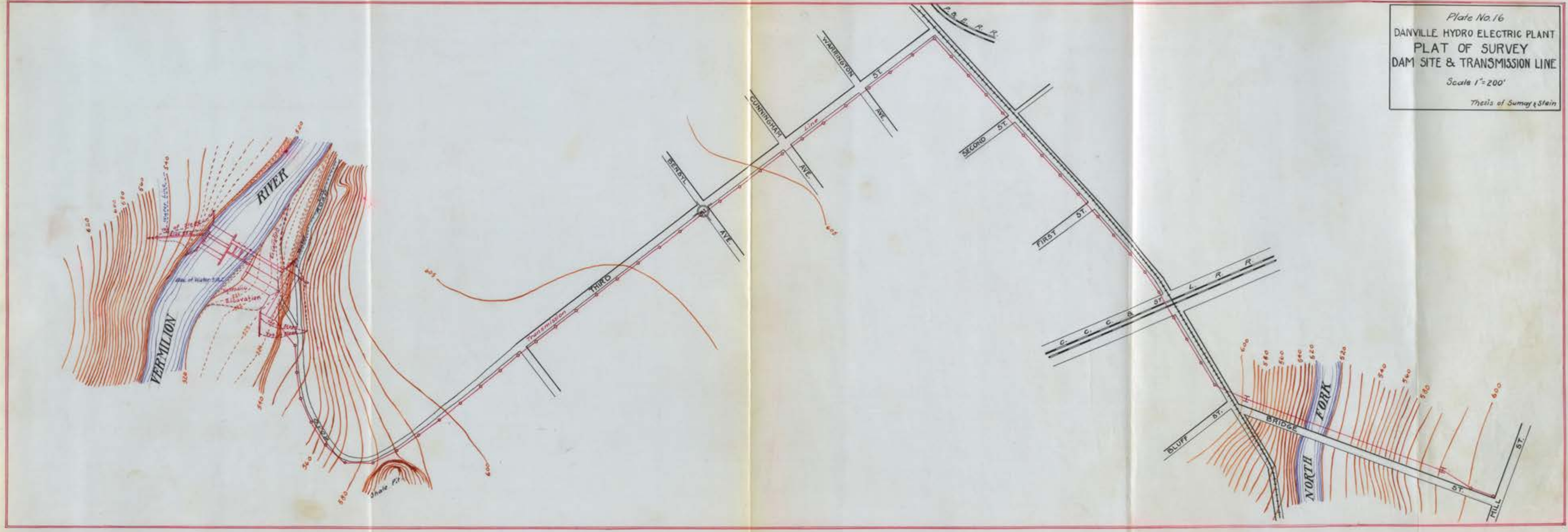


Plate No. 16
DANVILLE HYDRO ELECTRIC PLANT
PLAT OF SURVEY
DAM SITE & TRANSMISSION LINE
Scale 1"=200'
Thesis of Sumay & Stein
VERMILION
RIVER
NORTH
FORK
Transmission
Line
THIRD
ST.
BENSYL
AVE.
CUNNINGHAM
AVE.
WARRINGTON
AVE.
SECOND
FIRST
C. C. C. & ST. L. R. R.
P. & E. R. R.
BLUFF
BRIDGE
HILL
Shale Pit
605
600
580
540
520

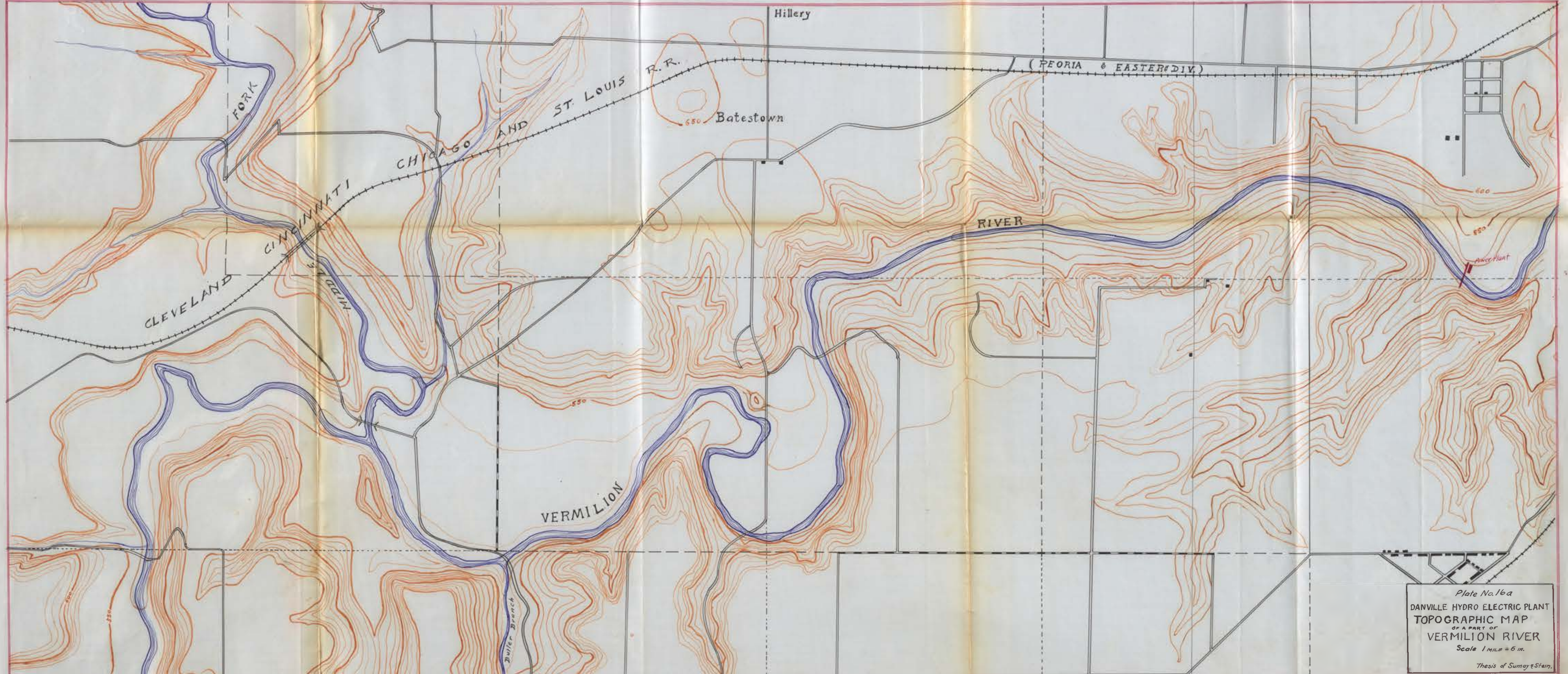


Plate No. 16a
DANVILLE HYDRO ELECTRIC PLANT
TOPOGRAPHIC MAP
OF A PART OF
VERMILION RIVER
Scale 1 MILE = 6 IN.
Thesis of Sumay & Stein.

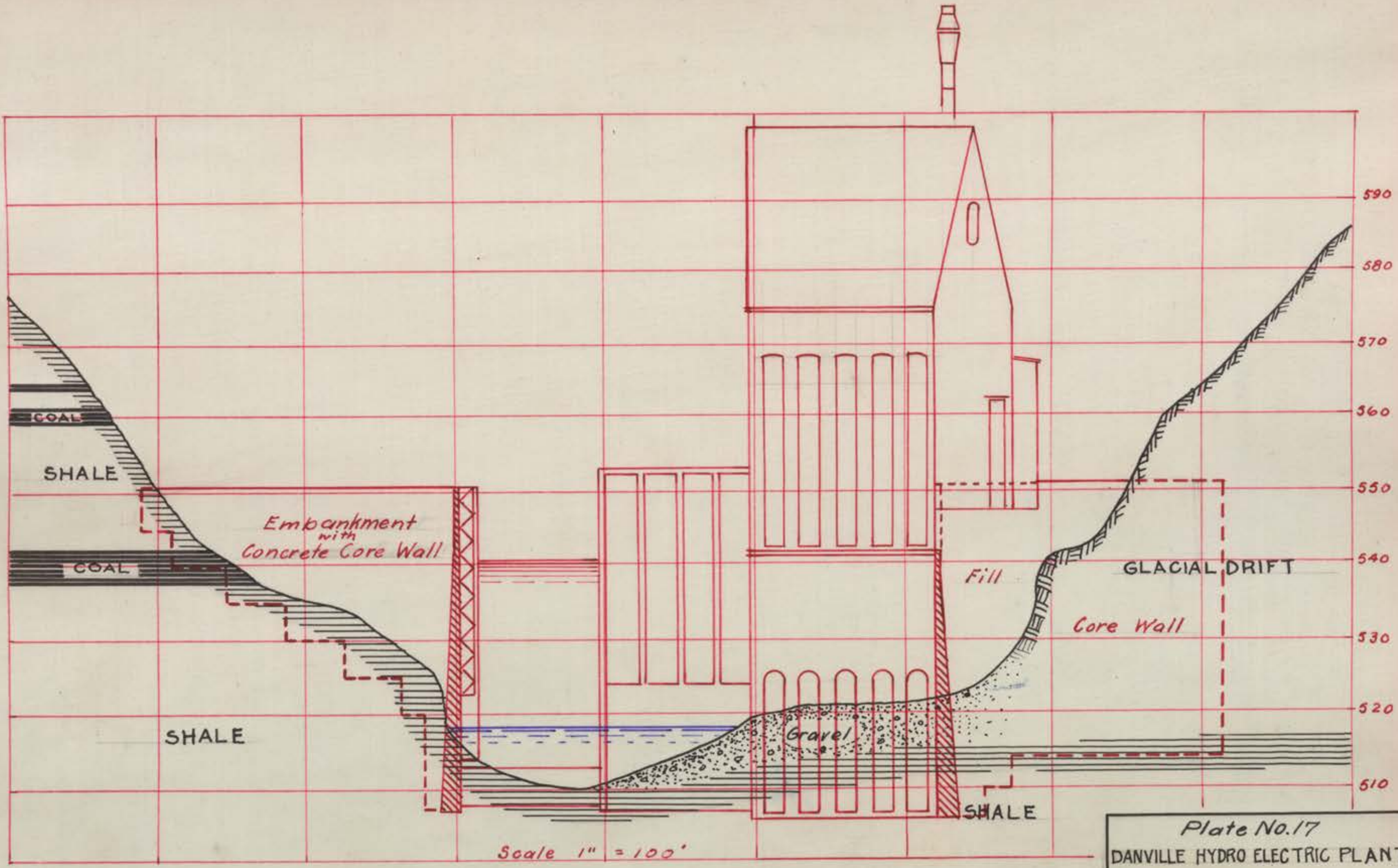
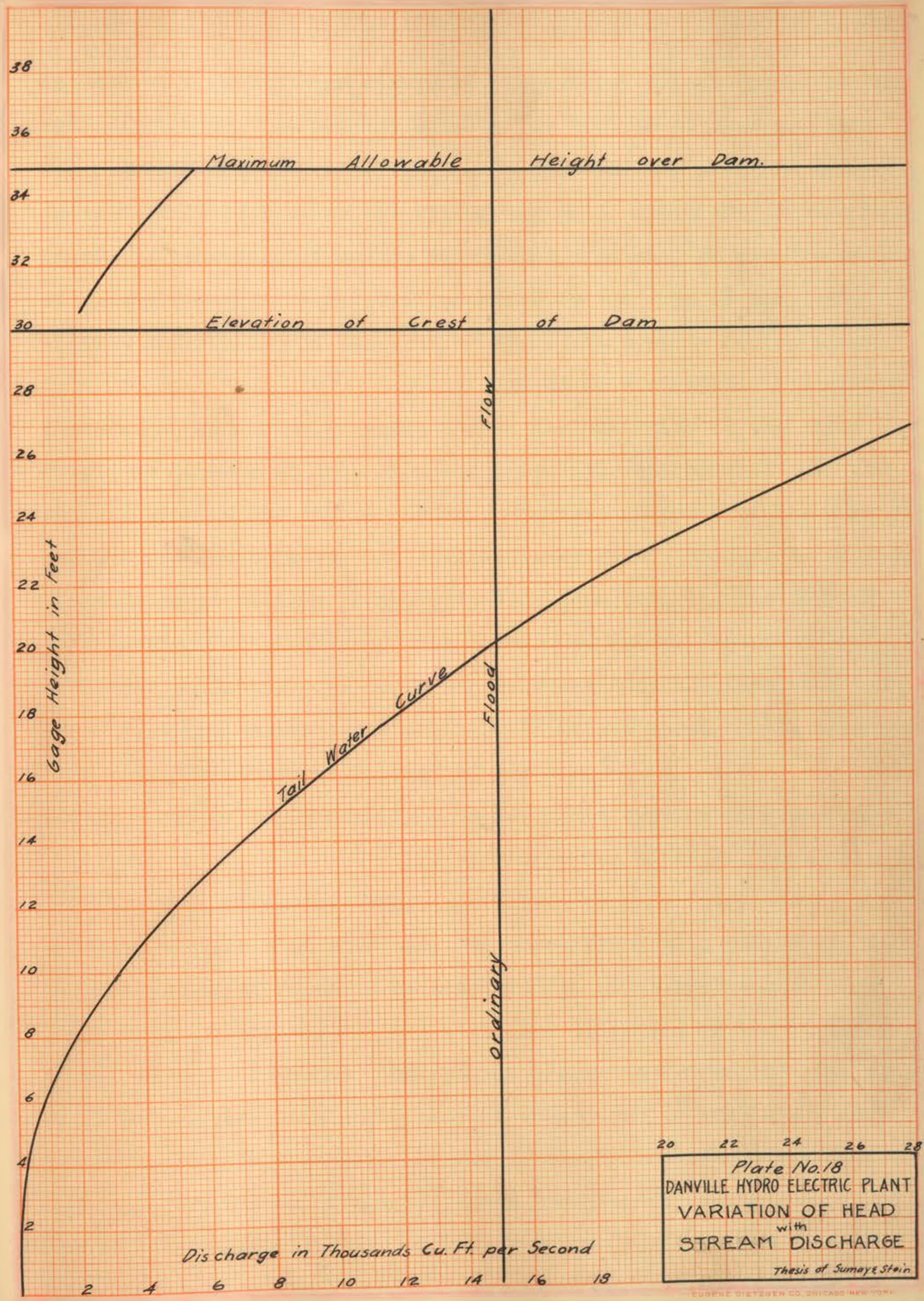


Plate No. 17
DANVILLE HYDRO ELECTRIC PLANT
SECTION OF DAM SITE

Thesis of Sumay & Stein


38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Maximum Allowable Height over Dam.
Elevation of Crest of Dam
Flow
Flood
Ordinary
Tail Water Curve
Gage Height in Feet
Discharge in Thousands Cu. Ft. per Second
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Plate No. 18
DANVILLE HYDRO ELECTRIC PLANT
VARIATION OF HEAD
with
STREAM DISCHARGE
Thesis of Sumay & Stein

is held at a rather high figure by the owners, prices quoted to the writers ranging from seventy five to one hundred dollass per acre. The probable reason for asking such a price is the possible existence of coal beds under the stream and this possibility should be carefully investigated before purchasing the land, as the disproving of it would result in a large reduction in the cost of the land.

GENERAL ARRANGEMENT OF THE PLANT: The various parts of the plant extend in a straight line across the stream and include, commencing at the west side of the river: first, an embankment with concrete core wall running back into the natural bank of the stream; second, the west abutment of the dam and the fish-way; third, the spillway section of the dam, of hollow concrete construction, eighty-five feet long; fourth, the Tainter gate section, consisting of four twenty foot gates, separated by four foot walls; then the power house, containing the turbines, generators and engines; and lastly, the boiler house, built with its long axis perpendicular to that of the dam.

GENERAL MODE OF CONSTRUCTION: A rather heavy type of concrete construction has been used thru-out, reinforcement being used where necessary. Many parts of the structure may seem heavier than necessary but these parts will generally, upon investigation, be found to be subjected to water pressure at some stage of the river, or to the weight and vibration of heavy machinary It has been the effort of the writers always to err on the side of safety where there was any chance of error, and to make every part thoroughly reliable rather than merely theoretically correct. The architectural effect of the buildings has been carefully considered, and while nothing elaborate in this line has been attempted, an effort has been made to have them symmetrically and pleasingly proportioned, while maintaining the appaarance of strength and simplicity.

METHOD OF DETERMINING SIZE OF SPILLWAY, FLOOD GATES, etc.: Before proceeding with a more detailed description it will be well to explain the method of proportioning the various hydraulic features of the plant. The size of turbines was first determined, as will be explained later under " Turbines ", and the quantity of water consumed by these found from tables given in the manufacturer's catalog. The amount of water required for the " head increasers " was also calculated as will be hereafter explained. A curve, such as is shown in Plate 18, was then constructed, giving the height of the tailwater (as determined by means of the stream flow data) as ordinates and the discharge of the stream as abscissas. A horizontal line was next drawn at a height corresponding to that of the crest of the spill-way above the bottom of the river. A second, parallel line was drawn representing the height to which the water might rise above the top of the dam, without causing damage to property adjacent to the stream. Evidently all the water up to the total discharge of the turbines (2255 cubic feet per second) may be passed thru these or the spillway, if it is desired to avoid running the plant . Should the discharge of the stream exceed the requirements of the turbines the surplus must pass over the spillway, and that in such a manner as to maintain a constant head, a very important consideration in the regulation of the current output. Therefore from a point whose abscissa is equal to the combined discharge of the turbines, and whose ordinate equals the height of the dam, a curve is drawn parallel to the tail water curve and the point at which this curve cuts the " maximum allowable flow " line gives the maximum discharge of the stream at which the spillway will control the water supply without diminution of head. This is found to be 6055 cubic feet per second, giving a discharge over the spillway of (6055 - 2255) or 3800 cubic feet per second. Since the height of water over the spillway at this point is five feet, the width is found to be 85 feet, using Francis' weir formula with c = 4.00, as determined for this form of dam. To avoid diminution of head after this point is reached, the " head-increasers" are called into play, and these satisfactorily control all discharges up to 14 000 cubic feet per second. The flood gates were designed to care for the difference between this and the maximum probable flood (31 500 cubic feet per second), a head of ten feet above the dam being allowed for this extreme condition, since such a flood would have a damaging effect even if no dam existed, and such damages would hardly be blamed on the obstruction of flow due to the power plant. The Tainter gates were figured as rectangular orifices, and are each capable of discharging 4000 cubic feet per second under a ten foot head. These calculations were checked by assuming different distributions of the available water supply, and the proportions here arrived at were found to answer for all cases. The various parts of the plant will now be described in detail.

THE SPILLWAY: The spillway is of reinforced concrete construction of the " gravity " type. It is composed of concrete slabs, both upstream and down, supported on butresses placed 10 feet center to center. The slabs were designed to withstand a water pressure due to a height of 10 feet over the crest of dam, and the downstream face was further strengthened to resist impact and abrasion due to the passing of heavy floods. The downstream face was given

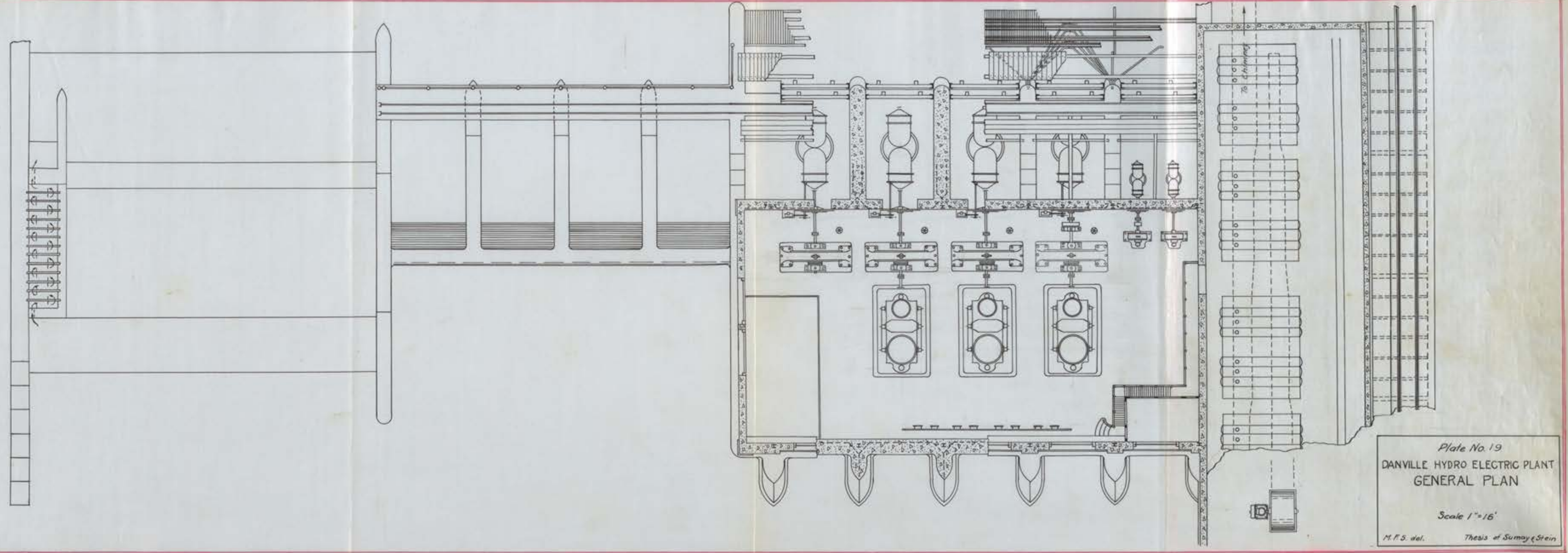


Plate No. 19
DANVILLE HYDRO ELECTRIC PLANT
GENERAL PLAN

Scale 1" = 16'

M.F.S. del.

Thesis of Sumay & Stein

an "ogee" shape so as to pass floods with as little disturbance as possible, and vent holes were provided on the down stream face just below the crest to admit air beneath the falling sheet of water and thereby prevent that peculiar vibration of the falling water which is so detrimental to the safety of dams. Drain pipes allow the water to escape from within the dam, and prevent the water from filling the dam in case of leaks in the upstream face. Weep holes in the bottom of the dam relieve it from all upward hydrostatic pressure. As an additional security against under-scouring the river bottom is riprapped for 100 feet below the toe of the dam. Calculations relative to the stability of the dam against overturning, shearing and crushing show it to have a minimum factor of safety of 4.9.

THE FISH-WAY: In compliance with the laws of the State of Illinois, a fish-way is provided to enable fish to pass the dam. This is built as a part of the spillway by extending a low wall down the front face of the spillway, parallel to and about eight feet distant from the west abutment, and dividing the channel thus formed into numerous compartments by wooden cross-baffles. The water is thus caused to pass from the higher to the lower level by a tortuous way and at a velocity sufficiently low to enable fish to swim upstream against it.

THE TAINTER GATES: The Tainter gates, four in number, are separated from each other by concrete walls four feet thick and extending well above high water. In their lower position the gates rest upon a low back wall extending between the dividing walls and built of reinforced concrete. The top of these back walls is composed of a heavy reinforced concrete beam, figured to sustain the weight of the gate. A tumbler bay is provided between the dividing walls by

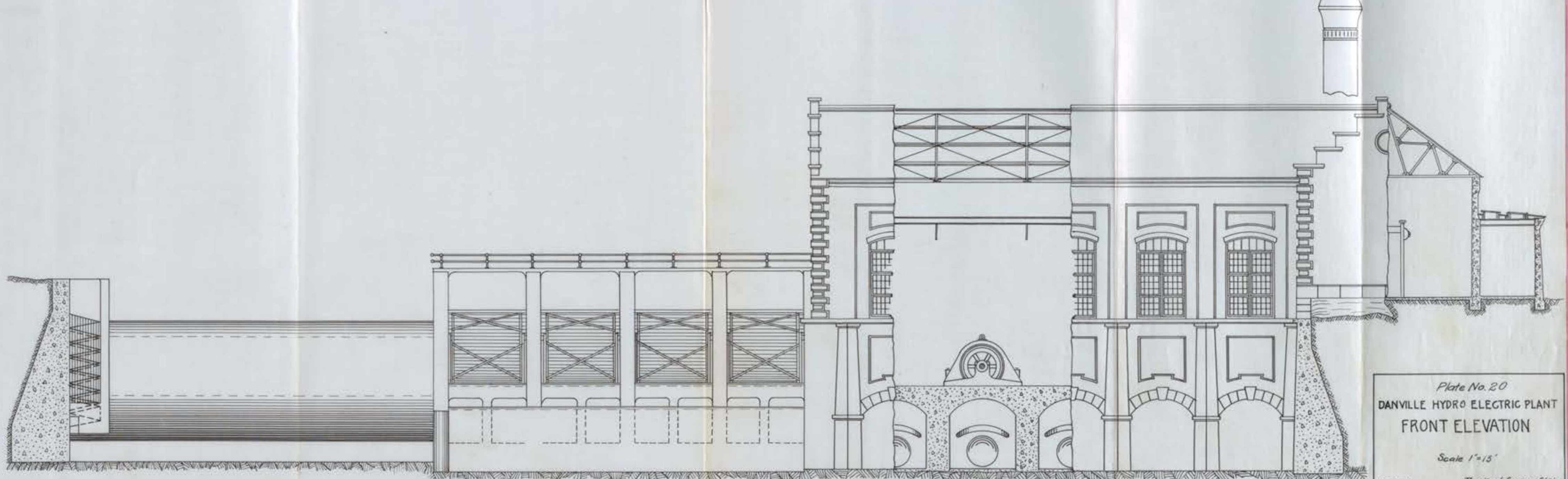


Plate No. 20
DANVILLE HYDRO ELECTRIC PLANT
FRONT ELEVATION

Scale 1" = 15'

H.F.S. del.
Thesis of Sumay & Stein

flooring the bed of the stream with concrete, and erecting a ten foot dam of solid concrete along the down stream side. Weep holes are provided to prevent any upward pressure of the water on the floor of the tumbler bays.

The gates proper are constructed of structural steel and are supported on trunnions embedded in the dividing walls. The faces of the gates are covered with steel plates, lapriveted, and varying in thickness from one - half inch to one - quarter inch depending on the water pressure to which they are subjected. To insure a water-tight joint between the gates and their seats, a four inches by nine inches timber is fastened to the lower edge of the gate, and rests on a two by eight inches timber bolted on top of the gate seat. Also, for the same porpose, flat rubber strips are bolted to the sides of the gate, which work on strips of sheet metal in the concrete of the dividing walls. A foot bridge composed of three I beams embedded in concrete runs over the gates, being supported on the dividing walls, and this is provided with a track along which runs a car provided with gear and tackle suitable for raising the gates. Each gate is equipped with two three - quarter inch chains, attached five feet from each end of the gate, and passing thru holes in the floor of the foot - bridge, so that , if it is desired to raise any gate, the hoisting car may be run into position over the gate, the chains attached to the hoisting drum, and the gate moved the required amount by hand or by a motor attached to the hoisting device. Grips hold the chains in any position, so that when the gate is properly adjusted, the grips may be fastened to the chains, after which the hoisting car may be moved on to the next gate, where the operation is to be repeated.

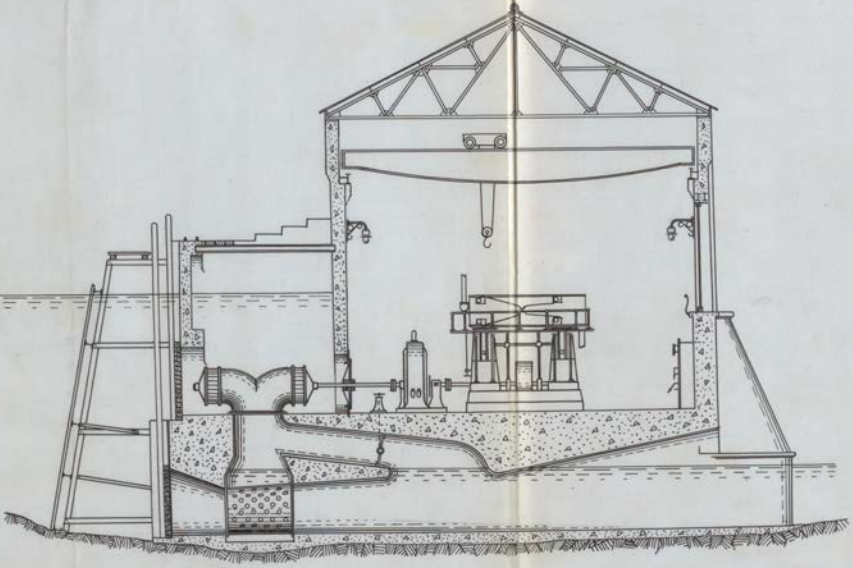


Plate No. 21

DANVILLE HYDRO ELECTRIC PLANT

SECTION THRU POWER HOUSE

Scale 1" = 16'

M.F.S. del. Thesis of [illegible]

THE POWER HOUSE: The power house is located on the east bank of the river. It is rectangular in shape, with its greatest dimension parallel to the axis of the dam and is 123 feet by 63 feet inside. The foundation consists of six massive concrete piers, parallel to the flow of the stream and having a minimum thickness of six feet. The power house floor is supported on heavy arches springing from the piers, and proportioned to resist the weight and vibration of the machinery. The space between the piers and below the arches serves to carry off the water after it has passed thru the turbines. The front and west walls, are four feet thick and are further reinforced and tied into butresses forming part of the piers, since during flood, the tailwater rises above the level of the floor of the power house, and consequently these walls are under water pressure. It was impossible to raise the floor of the power house, as this would have brought the turbines too near the surface of the head water during low stages of the river. The east wall of the power house is formed by the abutment along the east bank of the stream, while the up-stream wall separates the power house proper from the flumes and is designed to withstand water pressure to a height corresponding to the maximum high water to be expected above the dam. Above the maximum flood water, the walls are of ordinary concrete construction, 16 inches thick and slightly reinforced to prevent cracking. The roof is carried on six steel Fink trusses spaced 23 feet on centers, and consists of slate, laid on one inch white pine sheathing,supported by two by four inch rafters. The load is transmitted to the trusses by eight inch, sixteen and a quarter pound channel purlins spaced about seven feet on centers. One purpose of the wooden sheathing is to provide a non-condensing

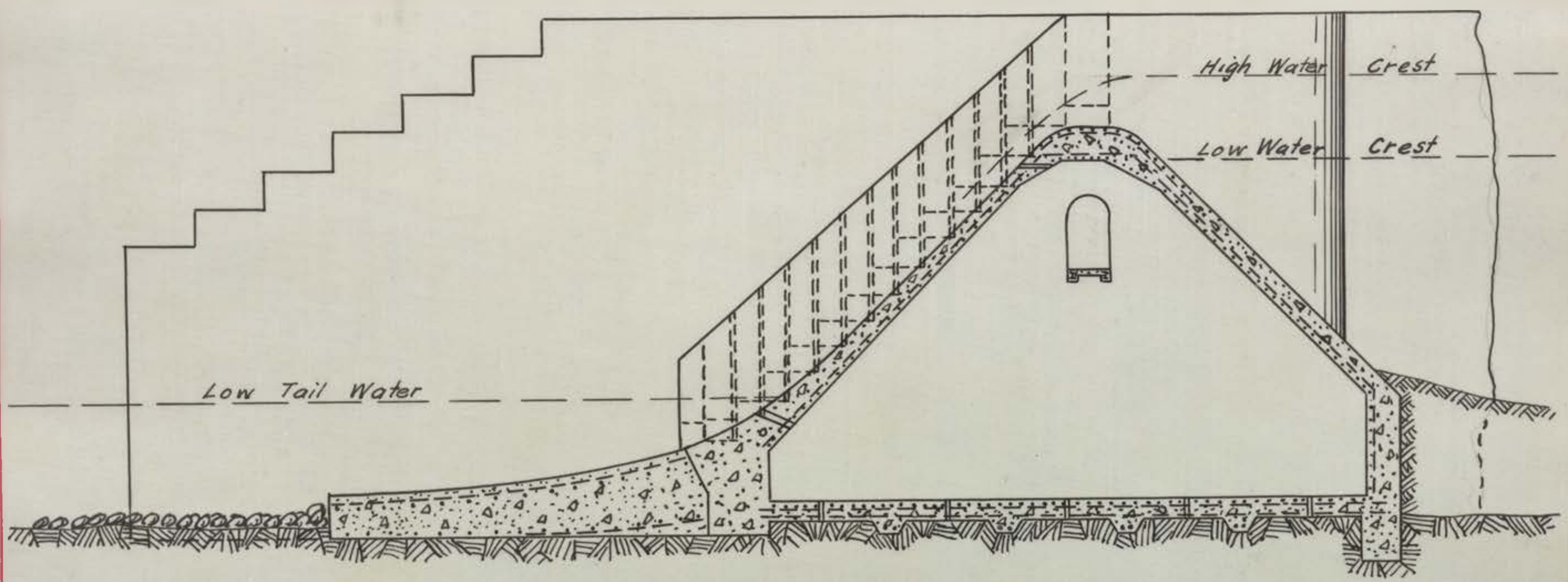


Plate No. 22
DANVILLE HYDRO ELECTRIC PLANT
SECTION THRU SPILLWAY
Scale 1" = 15'

M.F.S. del.   Thesis of Sumay & Stein

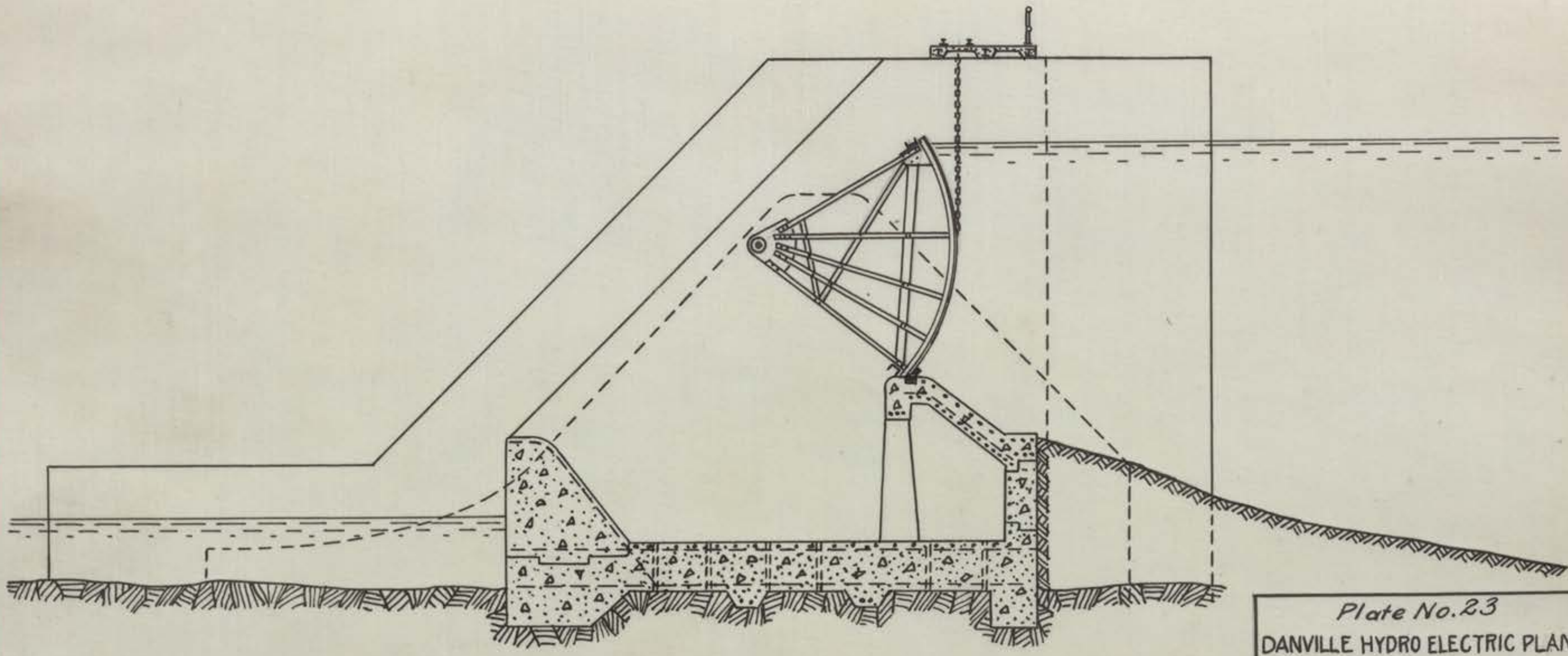


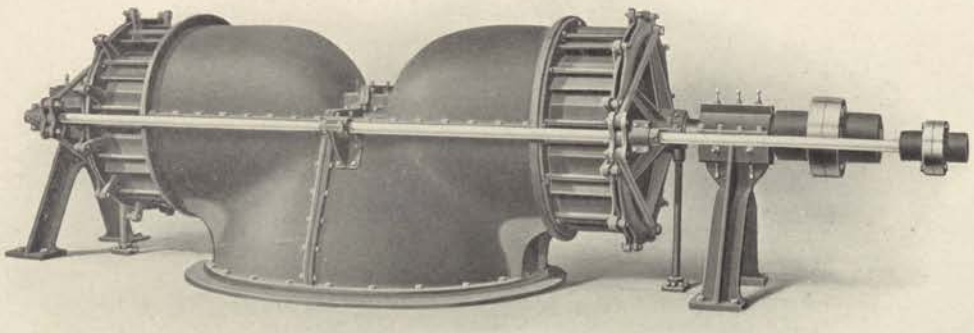
Plate No. 23

DANVILLE HYDRO ELECTRIC PLANT

TAINTER GATE

Scale 1" = 15'

Thesis of Sumay & Stein



Pair **48**-inch turbines arranged for open flume driving generator. Direct connected. Head 25 feet. **1340** H. P. **173** R. P. M.

Plate No. 24

DANVILLE HYDRO ELECTRIC PLANT

TURBINE

Thesis of Sumay & Stein

surface and prevent dripping due to the condensation of escaping steam.

The interior arrangement of the power house is shown on the accompaning general plan, Plate 19. The dynamos are placed in a line along the upstream side of the power house, each being direct-connected to a turbine, the shaft extending thru water tight bearings in a steel bulk-head in the upstream wall. These bulkheads are removable in order to facilitate repairs on the turbines. The engines are placed directly in front and on a line with the dynamos and may be connected to them when necessary by means of suitable flange couplings. The southeast corner of the power house is occupied by the office, which is supported on cast iron pillars so as to be on a level with the boiler house floor, with which it is connected by means of a balcony extending along the wall of the building. A stairway, leading from this balcony to the power house floor, makes the latter readily accessible from the office. The walls of the office are almost entirely of glass, which enables the engineer to observe the working of all parts of the plant. Directly beneath the office is the toilet and lavatory. The switch board is located near the downstream side of the building, and the south-east corner is fenced off, and is to be used as a tool room and repair shop. The power house is spanned by a 15 ton electric traveling crane running on a track supported on a 24 inch, 80 pound I-beam. The beams rest on columns built into the wall at intervals of 23 feet, the section of column being of I shape, built up of four 7″ x 3.5″ x 7/16″ angles and a 14″ x 7/16″ plate. For the position of minor details, auxiliary pumps, etc., the reader is referred to the piping plan, Plate 31.

THE FLUMES: The flumes are formed by an extension of the power house, the floors being at the same elevation and the dividing walls formed by carrying the piers which support the power house to an elevation above maximum high water. The upstream ends of the flume are closed by a wall, except that suitable openings are left for the admission of water to the turbines. These openings are fitted with wooden sluice gates, operated by means of the hoisting car mentioned under " Tainter Gates ", the track carrying this car over the Tainter gate section being for this purpose made continuous over the flumes, in order that any gate may be rapidly handled. The gates controlling the flow thru the head increaser are also manipulated in the same manner.

Before the water enters the flumes it passes thru a rack composed of 4 x 1/4 inch bars spaced 1 1/2 inches on centers, supported by a frame work of steel shapes. A wooden walk above the rack is provided for convenience in cleaning.

THE TURBINES: The turbines are of the twin vertical type, inward flow, built by the S. Morgan Smith Company, of York, Pennsylvania. The wheels are 48 inches in diameter and each unit is rated to give 1106.6 horse power at 172 revolutions per minute and with a 22 foot head. The regulation is effected by wicket gates, turned by a gate-shaft parallel to the shaft, three-fourth of a revolution sufficing to completely open the gates.

Each exciter is driven by a twin vertical 18 inch wheel, running at 433 revolutions per minute under 22 foot head.

TURBINE REGULATION: The turbines are controlled directly from the switch board. A potential coil is connected across the terminals of each unit, the armature of which swings between two contact points. When the terminal voltage is at the predetermined normal amount, the armature is not in contact with either piont, but any increase or decrease in voltage causes a deflection of the armature which makes contact on one side. This closes an electric circuit,and thru a relay excites a magnet operating a friction wheel, serving to transmit motion from a small shaft, continuously belt-driven by the turbine,to another shaft which operates a four way valve controlling an hydraulic cylinder. A piston in this cylinder acts on the turbine gate shaft thru the agency of a rack and pinion gear. To prevent hunting as far as possible, the circuit is automatically broken as soon as the four way valve is fully open in one direction or the other.

HEAD INCREASERS: The head increaser, used, as previously mentioned, to maintain a uniform head during periods of high water, when, as may be seen by reference to Plate 18 the tail water rises proportionately faster than the head water, is the invention of the eminent hydraulic engineer, Mr. Clemens Herschel, and is described by him in the " Harvard Engineering Journal ". The head increaser is merely a large venturi meter tube, with the turbine descharge entering at the point where the measuring tubes are usually attached. As is well known,there is often a tendancy toward the formation of negative pressure in the throat of the venturi meter when in operation, and Mr. Herschel greatly developed this tendency, partly by constructing the meters of a very large size, and partly by making them of a special form adapted to the end in view. The results obtained were very gratifying; to quote from the above mentioned article:"--------- the fall may thus readily be increased 50 per cent, which will cause the turbines to yield about 1.8 times the power they would naturally produce; on the well known principle of the power of a turbine varying as the 3/2 power of the fall, its own gate - opening remaining constant ". The theory of operation of the head - increaser is briefly as follows:

Let h = operating head.

h' = head gained

Q' = discharge of turbine due to the head $(h + h')$

Q = discharge of turbine under head h

Then $c\,Q\,h$ = work done by turbine without increaser.

and $c\,Q'\,(h + h')$ = work done by turbine with increaser.

Work gained by use of the increaser = W

$$W = Q' (h + h') - Q h$$

But since $Q : Q' = \sqrt{h} : \sqrt{h + h'}$

$$Q = \frac{Q' \sqrt{h}}{\sqrt{h + h'}}$$

or substituting

$$\text{work done} = Q' (h + h') - \frac{Q' h \sqrt{h'}}{\sqrt{h + h'}}$$

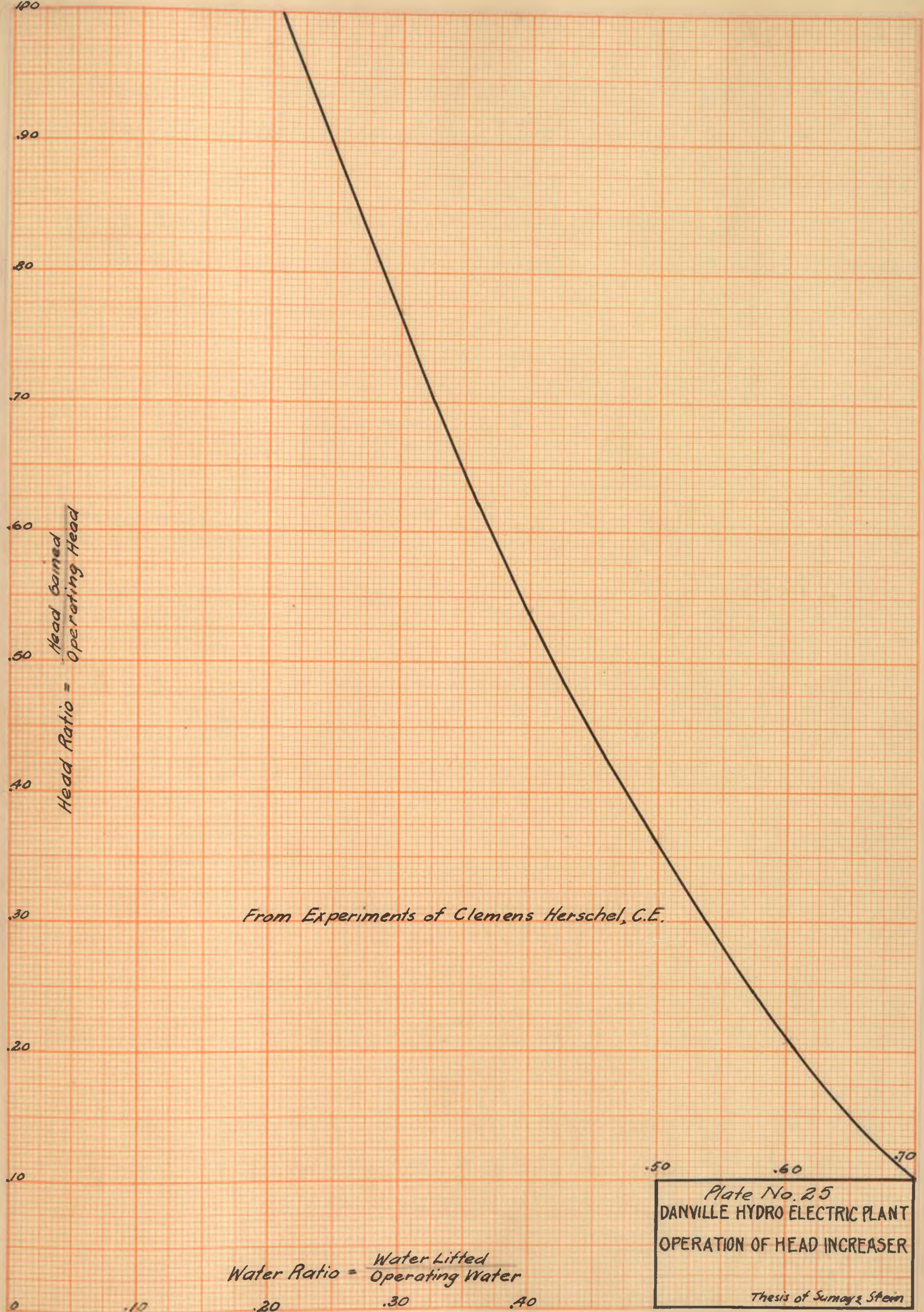
The efficiency of the increaser is

$$= \frac{Q' (h + h') - \dfrac{Q' h \sqrt{h'}}{\sqrt{h + h'}}}{\text{operating water} \times h}$$

Plate 25 gives the results obtained experimentally with a head increaser, ordinates representing efficiency and the ratio of head gained to the operating head, while the abscissas represent the ratio of the increased discharge thru the turbine to the operating water.

Applying the above to the present case, we have:

h = operating head (difference between head and tail water during high water) = 14 feet



1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
.10
.20
.30
.40
.50
.60
.70
Head Ratio = Head Gained / Operating Head
Water Ratio = Water Lifted / Operating Water
From Experiments of Clemens Herschel, C.E.
Plate No. 25
DANVILLE HYDRO ELECTRIC PLANT
OPERATION OF HEAD INCREASER
Thesis of Sumays Stein

h' = head to be gained (normal head (22 feet) - h) = 8 feet

Q' = discharge thru turbine under head ($h + h'$)

or 22 feet = 548 cu. ft./sec.

(Bulletin No. 100, p. 15, S. Morgan Smith & Co.)

Q = discharge under head h(= 14 feet) = 438 cu.ft./sec.

Referring to Plate 25.

$$\text{The required head ratio} = \frac{\text{head gained}}{\text{operating head}} = \frac{8}{14} = .57$$

$$\text{For this ratio } \frac{\text{water lifted}}{\text{operating water}} = .38 \text{ or}$$

$$\text{Operating water} = \frac{\text{water lifted}}{.38}$$

Water lifted = discharge of turbine under head ($h + h'$)

or 22 feet = 548 cu. ft/sec.

$$\text{Whence: Operating water} = \frac{548}{.38} = 1440 \text{ cu. ft./sec.}$$

Considering the entrance to the head increaser as a converging tube, the required area may be found from the equation:

$$Q = c\, a \sqrt{2\, g\, h}$$

where Q = 1440 cb. ft./sec.

c = 0.85

h = 14 feet

and a = area to be found.

Substituting and solving, we get

$$a = 56.6 \text{ square feet}$$

This is equivalent to a circle of 8.5 feet diameter. By referring to the sectional view of the power house it will be seen that the discharge from the turbines normally is ejected thru a curved draft tube, which during high water is closed by means of a butterfly gate, the water then passing vertically downward and thru the head increaser.

GENERATORS: The generators, which are of the alternating current type, were designed for a total capacity of 3140 K. W., this being the capacity of plant decided on (see page 19). Since the transmission line is very short, it was thought best to use a low voltage, thus saving the cost of step-up transformers, which more than balanced the additional cost of the larger wires of the transmission line. The voltage chosen was 6600 volts, this being a standard value. In choosing the proper speed for the generators, the capabilities of the turbines chosen were carfully considered, as these are limited to a narrow range of speed under a given head. An approximate speed of about 170 revolutions per minute was decided upon.

Number of Poles and Speed of Generators: After the approximate speed of the generators had been decided on, the actual speed was found as follows:

Considerations: Since the electric power to be supplied at the bus bars was 3140 K. W. , and the generators are assumed to have an efficiency of 93 per cent, the input of them must be

$$\frac{3140}{.93} = 3373 \text{ K. W.}$$

In order to have a good and economical service, the total input was divided into four units of

$$\frac{3140}{4} = 785 \text{ K. W. each.}$$

and since current is to be supplied for both lighting and power, a frequency of sixty (60) was chosen. The distribution system selected was three phase, because it secured economy in the transmission line, and facilitated a better motor operation and power distribution.

Poles: The number of poles required for these generators is given by the equation

$$p = \frac{2\,f}{n} \qquad (1)$$

where p = number of poles in the magnetic field of the generator.

f = frequency in cycles per second.

n = revolutions per minute.

and the constant 2 is used because there are p/2 pairs of poles.

then, substituting in (1)

$$p = \frac{2 \times 60 \times 60}{170} = 42.4 \text{ poles.}$$

Taking 42 poles and solving equation (1) for n, to obtain the actual speed in revolutions per minute:

$$n = \frac{2 \times 60 \times 60}{42} = 172 \text{ R. P. M.}$$

Floor Space Occupied by each Generator: Owing to the low speed at which the generators are to work, which is one of the characteristics of low head hydro - electric installations, they must be special-order machines, and to obtain an approximate measure of the floor space occupied by each of them, the diameter of the armature and the axial length of the poles were calculated, using suitable constants.

The following method is given by Mr. G. Esterline in his book " Alternating Current Machine Design ":

Diameter of the Revolving Field: The peripheral speed V in a revolving piece of machinary in inches per minute is equal to

$$V = \pi d n.$$

where d = diameter of the revolving piece in inches

n = speed in revolutions per minute,

or reducing the peripheral speed to feet per minute

$$12 V = \pi d n \qquad (2)$$

The limit of this peripheral speed V must lie between 5000 to 8000 feet per minute.

A rule to get an approximate value of V is that

$$V = 100 f \quad \text{feet per minute.}$$

where f = frequency.

Substituting:

$$V = 100 \times 60 = 6000 \quad \text{feet per minute.}$$

which lies within the above limits, and is the value we shall assume in these calculations.

Substituting this value of V, in equation (2) and solving for d, we obtain

$$d = \frac{6000 \times 12}{3.14 \times 172} = 133.3 \quad \text{inches}$$

Circumferential Width of the Pole Piece: Since the generator will have 42 poles, the width (W_p) of the pole piece can be easily found if we assume that, of the total circumference, 65 per cent will be occupied by the pole pieces.

then

$$\frac{W_p \times p}{.65} = \pi . d$$

where p = number of poles in the machine.

Substituting and solving for W_p

$$W_p = \frac{-3.14 \times 133.3 \times .65}{42} = 6.5 \text{ inches}$$

That is, the peripheral length of each pole piece will be 6.5 inches.

Total Flux Φ: The total flox Φ is given by the equation

$$\Phi = \frac{E\ 10^8\ b}{p\ Z\ n\ K} \qquad (3)$$

where E = voltage 6600

b = number of parallel paths 1

p = number of poles 42

Z = number of conductors per pole (to be found)

n = revolutions per minute 172

K = is a constant depending on the spread of the armature coil in per cent of the pole pitch (where spread is the ratio of the pole pitch covered by the winding of one phase, to the total pole pitch)

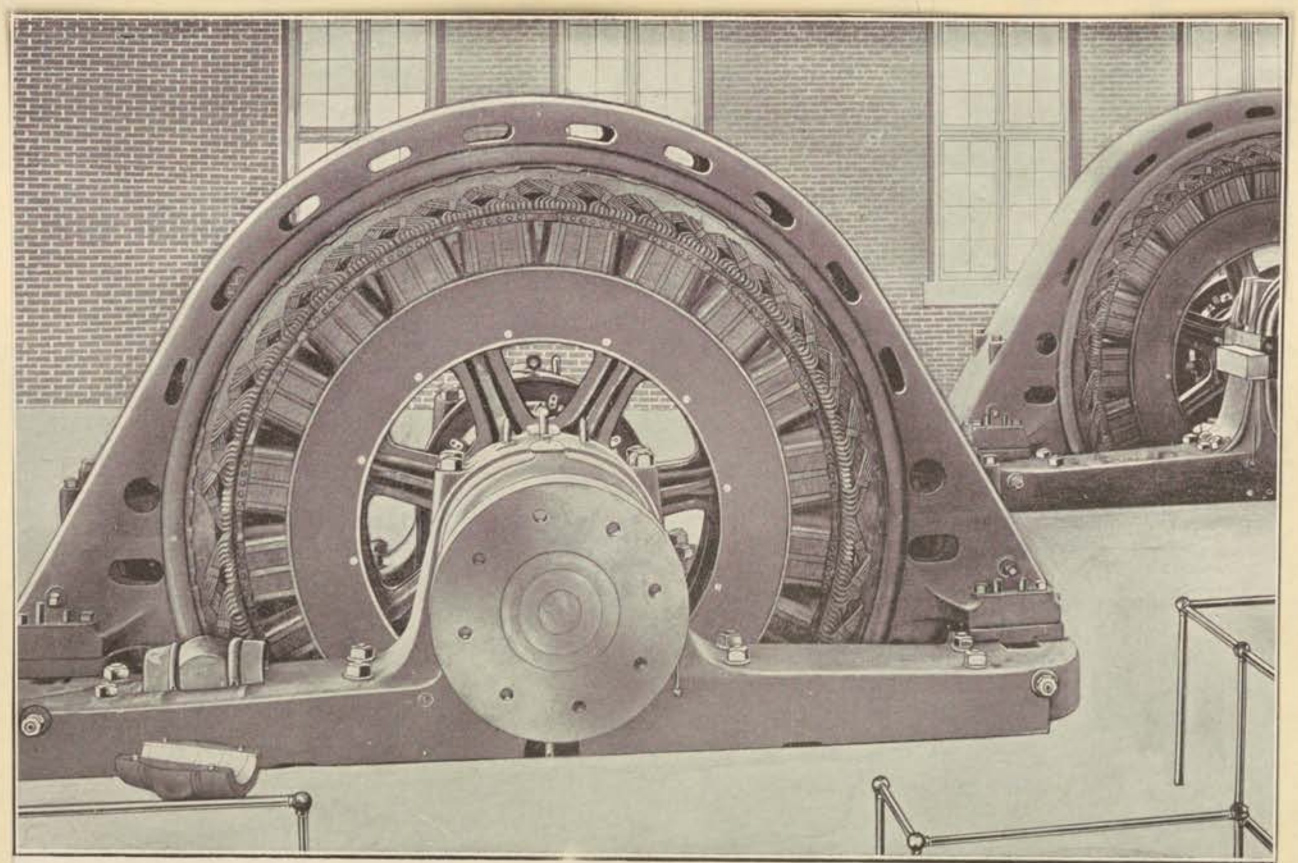
In order to solve equation (3) we need to know the values of Z and K.

Value of K: As the difference between the width of the teeth and that of the slot is very small, we may consider that they are of equal width; and, since, as a rule, we have six slots per pole, we have then, two slots per phase per pole, this being a three phase machine. And since the width of the slots and teeth is equal, there will be 6 x 2 = 12 spaces per pitch, and the spread ratio will be

$$\frac{\text{slots per phase per pitch}}{\text{spaces per pitch}} = \frac{3}{12} \quad \text{or } 25\ \%$$

This value is of course too high, because of the insulation on the slots, and it would be more exact to take 20 per cent instead 25 %.

Refering to table 1X, on page 64 of the above mentioned book,



785 K.W. THREE-PHASE, 6600-VOLT REVOLVING FIELD ALTERNATORS
In the Power Station of the Danville Hydro Electric Plant, Danville, Illinois.

Plate No. 27
DANVILLE HYDRO ELECTRIC PLANT
GENERATOR

Thesis of Sumay & Stein

and using the spread ratio, 20 per cent, the value of K is found to be 1.19.

Value of Z: Assuming the air gap to be one half inch, the diameter of the armature face will be

$$133.3 - 2 \times 1/2 = 134.3 \text{ inches}$$

and the periphery of the armature face becomes

$$134.3 \times 3.14 = 422 \text{ inches.}$$

Assuming 190 ampere turns per inch, the total ampere turns will be

$$422 \times 190 = 80\ 200 \text{ ampere turns}$$

and since the current per machine is

$$I = \frac{785\ 000}{6600 \times 3} = 69 \text{ amperes}$$

the turns per phase will be giveh by

$$Z = \frac{2 \times \text{ampere turns}}{\text{current} \times 3}$$

where 3 = number of phases

then,

$$Z = \frac{2 \times 80\ 200}{69 \times 3} = 774 \text{ turns}$$

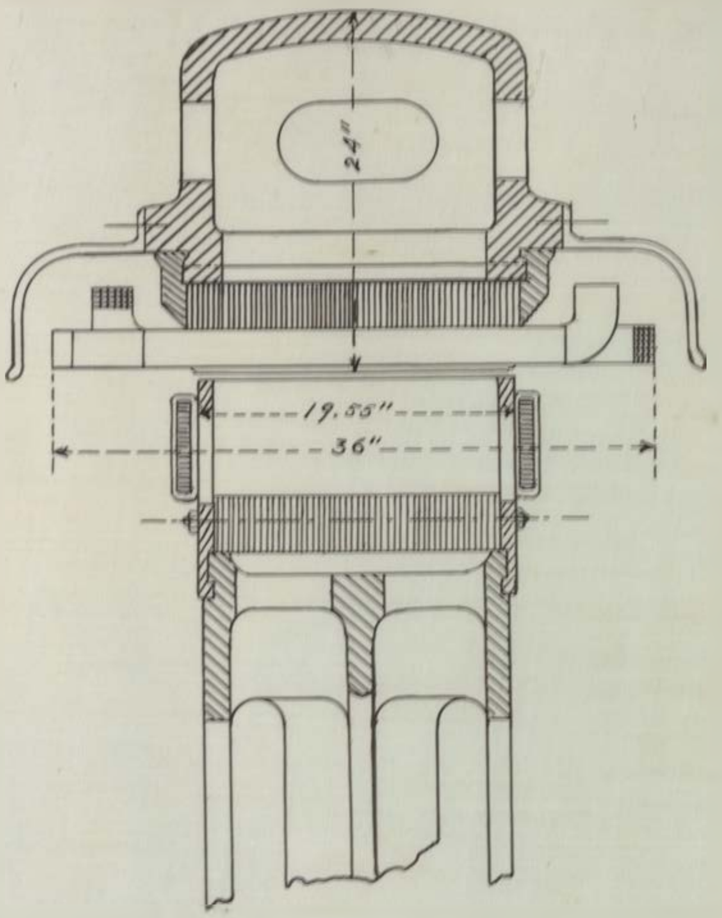
Now since all the unknown quantities in equation (3) have been found the total flux per pole can be obtained by substitution

$$\Phi = \frac{6600 \times 10^8 \times 1 \times 60}{42 \times 774 \times 172 \times 1.19} = 6\ 360\ 000 \text{ lines}$$

Assuming 50 000 lines of force per square inch in the air gap (=B), the total area of the pole face will be

$$\frac{\Phi}{B} = \frac{6\ 360\ 000}{50\ 000} = 127 \text{ inches}$$

and since the circunferential width of the pole face was found to be 6.5 inches, the axial length will be



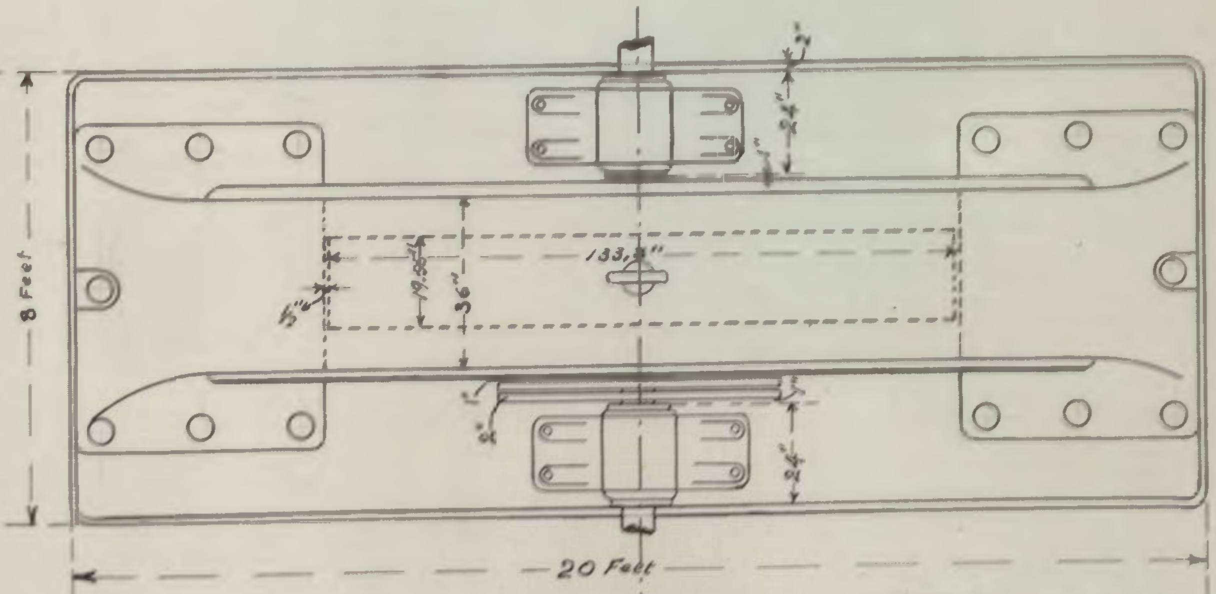


Plate No. 27

DANVILLE HYDRO ELECTRIC PLANT

DETAILS OF GENERATORS

Scale 1" = 2½'

Thesis of Sumay & Stein

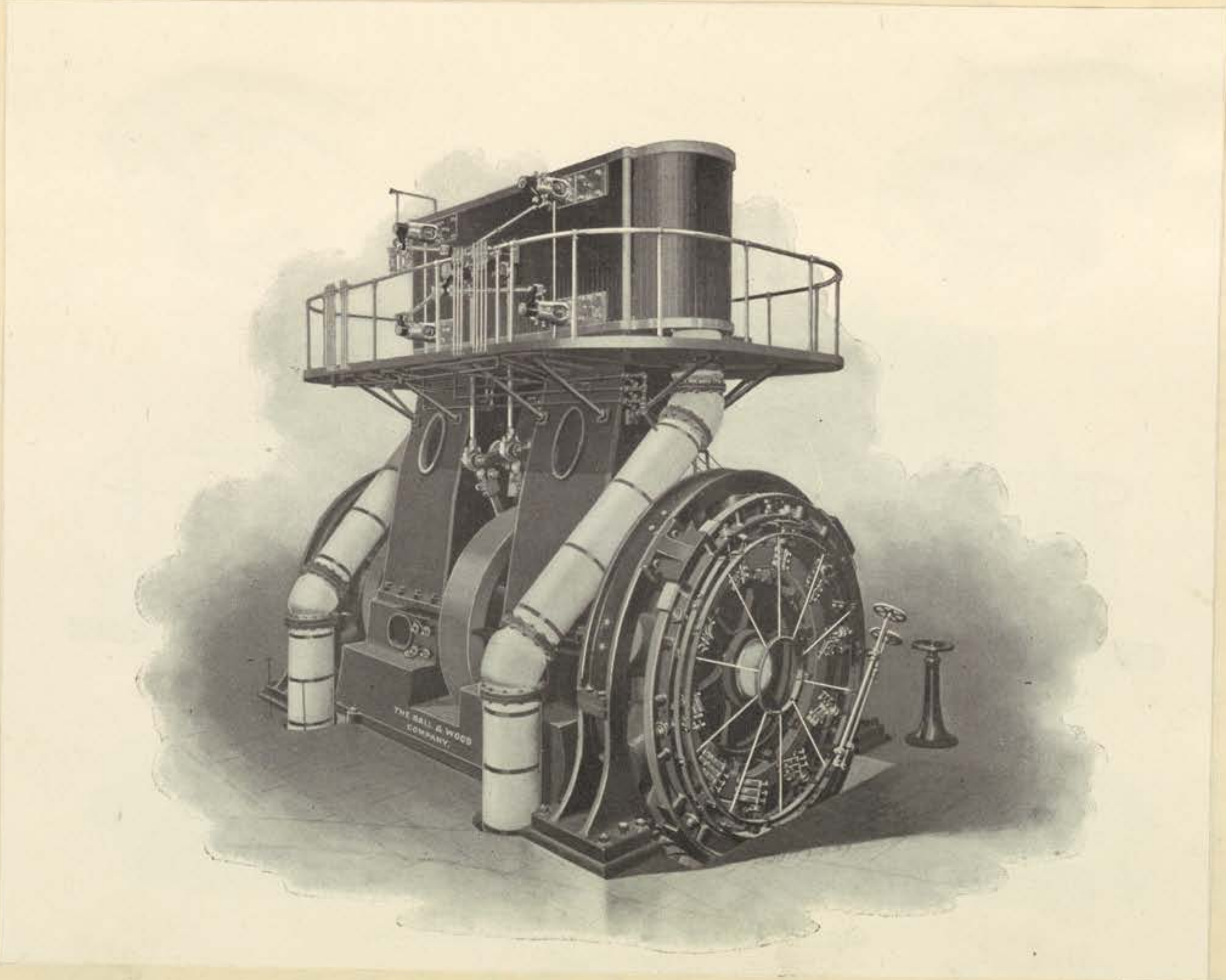


Plate No. 28
DANVILLE HYDRO ELECTRIC PLANT
BALL & WOOD ENGINE

Thesis of Sumays Stein

$$\frac{127}{6.5} = 19.55 \text{ inches}$$

This gives an idea as to the width of the generator. By making a proportional sketch of this machine showing the field, armature, air gap, etc. in proper relative positions, the floor space required is found to be eight by twenty feet, as shown in Plate 27.

The following table gives a recapitulation of the principal factors governing the design of the generators, such as would accompany the order to the manufacturer and would form a basis for the specifications:

Total capacity at the switch board	3140 K. W.
Number of units	4
Efficiency of generators	93 %
Voltage of units	6600 Volts
Frequency	60 Cycles
Winding	3 Phase

EXCITERS: Assuming that the capacity of each exciter will be 2.5 per cent of the total capacity of the power plant, since this capacity is 3140 K. W., the rating per exciter will be

$$\frac{3140 \times 2.5}{100} = 78.5 \text{ K. W.}$$

The current output at 110 volts will be

$$\frac{78.5}{110} = 714 \text{ amperes}$$

assuming that the voltage of exciters is 110 volts.

The exciter chosen was a 84.5 K. W., 110 volts direct current machine, made by the Westing house Manufacturing Company (catalog number 1156). All dimensions were obtained directly from this catalogue. To provide for breakdowns, two machines were installed, each driven independently by a 110 horse power Morgan and Smith turbine. As a further precaution, means were provided for driving one exciter unit directly from a main generator shaft by suitable belting.

ENGINE: It was found by the load curve that a peak load of 4200 horse power must be provided for at the bus bars. By assuming 93 per cent efficiency for our generators, the brake horse power of the engines must be

$$\frac{4200 \times 100}{93} = 4520 \text{ H. P.}$$

But of this capacity 1/4 is going to be water power even at the minimum stage of the river, leaving the engines to furnish

$$\frac{3 \times 4520}{4} = 3390 \text{ H. P.}$$

In order to work the engines efficiently it is better to divide this capacity into three units of 1130 horse power each, and connect them directly to three generators, because during the worst condition of the river there will be enough water available to run one generator. As these engines are to remain idle the greater part of the time, it would not be advisable to use condensing engines. However, the exhaust steam will be used for heating the feed water. Then the specifications for the engines would be:

Three non-condensing engines

Capacity 1100 brake horse power

Pressure 150 pounds gage

Speed 172 revolutions per minute.

Engines manufactured by the Ball and Wood Company meet these conditions and will be adopted. In the catalog published by these manufacturers, data is available for a 1000 horse power and 1300 horse power and by interpolating the following very close approximation as to floor space and over all dimensions was obtained for the machines under consideration.

Capacity		1100 H. P.
Speed		172 R. P. M.
Floor space	length	25 ft. 2 in.
	width	15 ft. 4 in.
Diameter of steam pipe		9 in.
Diameter of exhaust pipe		14 in.
Approximate weight		19 000 pounds.

THE BOILER HOUSE: The boiler house is similar in construction to the power house and is placed on the bank of the stream 24 feet above the floor of the power house, avoiding danger of floods during high water. The boilers are built along the wall nearest the power house and extend a little beyond the center of the building. A narrow gage track is built in front of them, to facilitate the handling of coal and ashes. A coal bin extends along the east side of the building, and arrangements are made whereby the coal cars may be run onto a track extending over this bin and may discharge coal directly into it. The forced draft machinery is located in the south west corner of the building.

BOILERS: The boiler capacity was found by the following method:

The steam consumption of high speed compound non-condensing engines as given by Mr. Henry C. Meyer in his book on "Steam Power Plants" is from 24 to 26 pounds of steam per I. H. P. per hour at a pressure of 150 to 160 pounds gage. As can be seen this data fits our case very closely. Using these values as a basis, we shall assume a steam consumption of 25 pounds per indicated horse power per hour at a pressure of 150 pounds gage. We may then calculate the size of boiler required to provide the 3390 engine brake horse power.

Statement as to conditions governing calculation of boiler capacity:

Efficiency of engines	85 %
Steam consumption	25 lbs/IHP/hr
Boiler pressure	150 lbs.gage
Capacity of each boiler (assumed)	600 boiler HP
Illinois coal to be used. Calorific value	12000 B.T.U.
Plenty of exhaust steam being available the feed water may be brought to a temperature of	200 F.

Calculation: The total amount of steam consumed per hour is

$$Q = \frac{25 \times 3390}{.85} = 100\ 000 \text{ pounds.}$$

The total heat units in B. T. U. contained in each pound of steam at the boiler pressure, 165 pounds absolute, is equal to

$$\lambda = q + r$$

where q = heat of liquid = (at 165 lbs. absolute) 337.7 B. T. U.

r = heat of vaporization = " " " 855.9 "

But of this quantity of heat only ($\lambda - q_1$) need be provided for, since q_1 represents the quantity of heat already in the feed water; then, the additional B. T. U. which are required in producing 100 000 pounds of steam per hour will be

$$= 100\ 000(1193.6 - 168.2) = 102\ 540\ 000 \text{ B. T. U.}$$

where q_1 = 168.2 B. T. U. corresponding to 200 F., temperature of

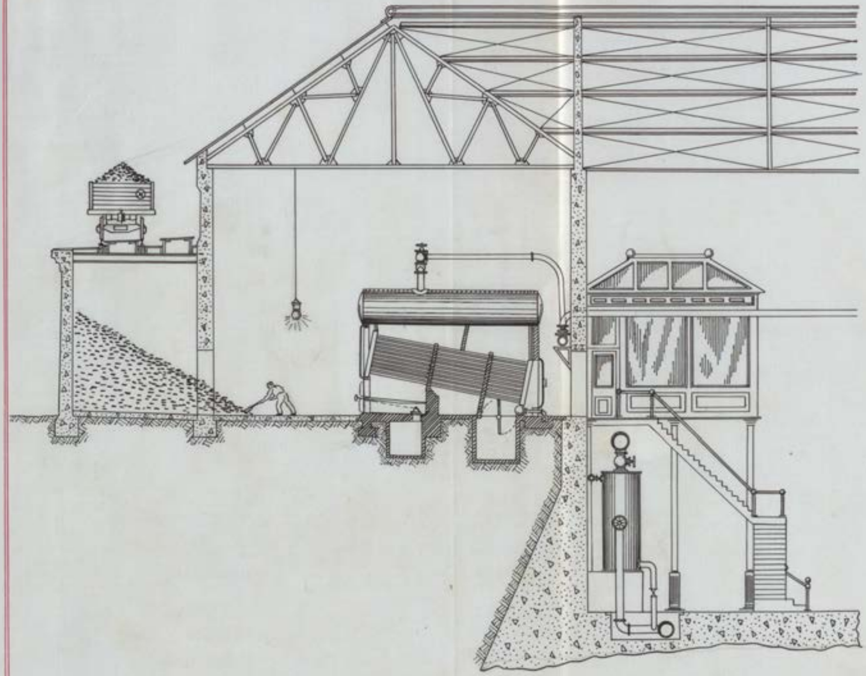


Plate No. 29
DANVILLE HYDRO ELECTRIC PLANT
SECTION THRU BOILER HOUSE
Scale 1" = 10'
Thesis of Sumey & Stein

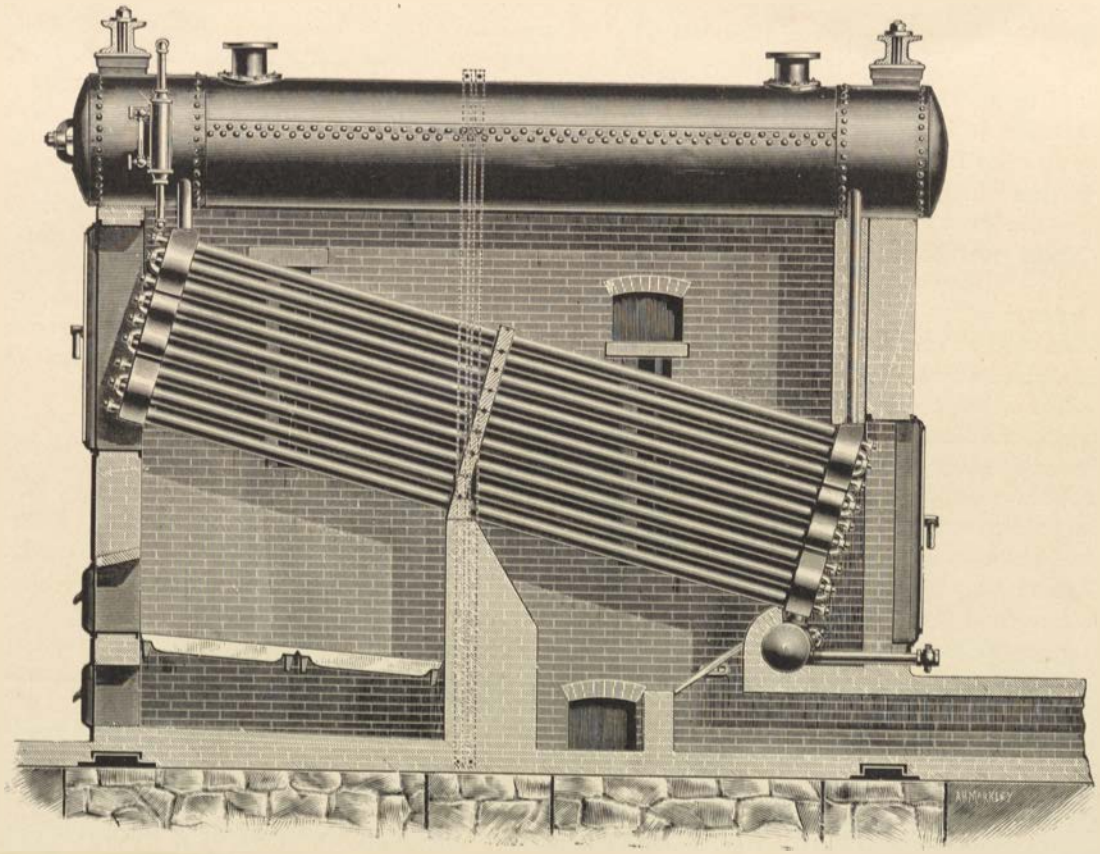


Plate No. 30a.

DANVILLE HYDRO ELECTRIC PLANT

SECTION OF BOILER

Thesis of Sumay & Stein

feed water.

Now, since a boiler horse power is produced when 34.5 pounds of water per hour are evaporated from and at 212 F., and 966.3 B. T. U. are required to vaporize one pound of water from 212 F., then, the boiler horse power required to produce 102,500,000 B. T. U will be

$$\frac{102\ 540\ 000}{345 \times 966.3} = 3080 \text{ B. H. P.}$$

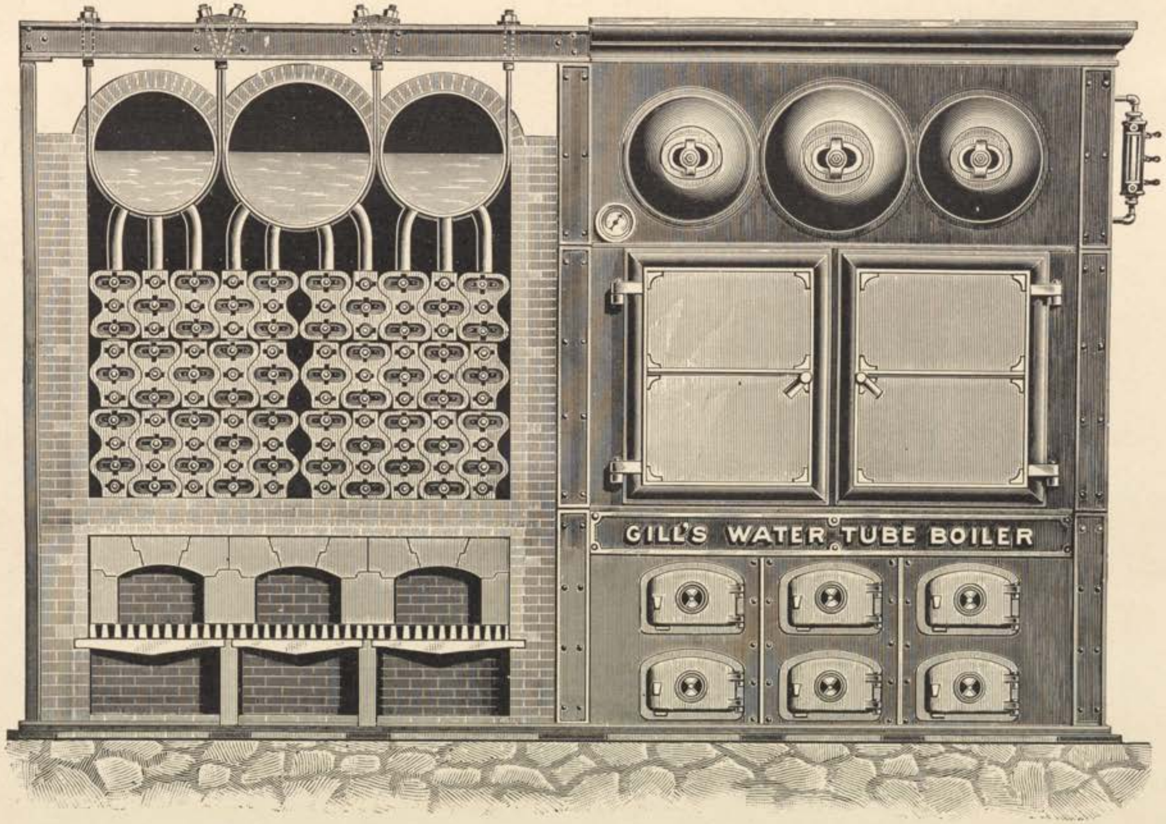
which is the capacity of the boilers. Since there are five sets of boilers the capacity of each set will be

$$\frac{3080}{5} = 616 \text{ Boiler H. P.}$$

or according to the statement made above as to the operating conditions of power plant we may use a boiler set of 600 Boiler H. P.

General Boiler Data as Obtained from Catalogue: The type of boiler chosen is the Gill's Water Tube, build by the Stearns; Steam Manufacturing Company. Each set has two boilers and each boiler three drums.

Description	Horse power of boiler	600
	No. of boiler	358.5
	Class	D. I.
	Headers width	22 inches
	Tubes	10 feet high
	"	17 feet long
Drums	Diameter of one drum	34 inches
	Diameter of two drums	42 inches
	Length	20 feet 3 inches
Heating surface	Tubes	5874 square feet.
	In drums	534 " "



Single Boiler, 300 H. P. *Single Boiler, 300 H. P.*

Two Boilers, arranged as above, in One Battery, 600 H. P.
Arranged with one row of tubes less than above shown.

Plate No. 30b.
DANVILLE HYDRO ELECTRIC PLANT
BOILERS.

Thesis of Sumay & Stein.

Heating surface	Total	6438 square feet
Grate surface	Length of furnace	7 feet
	Width " "	22 feet 4 inches
	Total grate surface	158 square feet
Floor space occupied	Width of brick	27 feet 8 inches
	Length of drum	20 " 5 "
	Height to top of beams	20 " 3 "
Miscellaneous	Number of bricks	36 000
	" " fire bricks	6 000
	Weight of boiler	127 000 pounds.

DRAFT: It was first thought best to use natural draft and calculations were made with this end in view, but owing to the very large chimney required, it was found that the cost was excessive. The chimney designed was to be of concrete, 150 feet high, and 12 feet inside diameter, and the estimated cost amounted to about 6000 dollars. As compared to this a forced draft system was considered. This was designed as follows: The quantity of air required per pound of coal burnt was taken as 300 cubic feet - an average value. The number of pounds of coal burnt per boiler horse power per hour is found as follows:

$$\text{Pounds of coal} = \frac{\text{Total consumption of heat in B. T. U.}}{\text{Heat per pound of coal} \times \text{efficiency}}$$

Assuming a boiler efficiency of 75 per cent, the amount of coal burnt to produce the 102 540 000 B. T. U. per hour, will be

$$= \frac{102\ 540\ 000}{12\ 000 \times .75} = 11\ 400 \text{ pounds/hr.}$$

and the amount of air required per minute is:

$$\frac{300 \times 11\ 400}{60} = 57\ 000 \text{ cubic feet}$$

By refering to a manufacturer's catalog it was found that the required fan must be 10 feet in diameter, running at 150 revolutions per minute and requiring an engine of 25.8 horse power. A comparison of the costs will now be made:

1. Chimney:

1st. Cost	$ 7 000
Depreciation (2% of cost per year capitalized at 4 %)	$ 3 500
Maintenance	0
Total	$ 10 500

2. Forced Draft System:

1st. Cost	
1- 10 ~~inch~~ foot fan	$ 900
1 - 30 horse power engine	$ 500
Depreciation on above (4 % per annum capitalized at 4 %)	$ 1 400
Operation (figured at 3 months continous running per year, capitalized at 4 %)	$ 2 700
1 - 80 x 8 feet chimney	$ 2 500
Depreciation on same, capitalized as above	$ 1 250
Total	$ 9 250

This shows a saving of $ 1250 in favor of the machanical draft system. In addition to this, the flexibility of such a systwm must be considered, an item of great importance in a plant such as this, subjected to large peaks and great variations of load.

Size of Flues: 1. Cold air conduits. Computations as to the size of flues were made as follows:

Quantity of air required to be furnished by the fan (at 60° F.) equal 57000 cubic feet per minute.

Velocity of air in flues equal 2000 feet per minute (assumed).

$$\text{Required area} = \frac{57000}{2000} = 28.5 \text{ square feet.}$$

Make flues 5 x 6 feet.

Since there are five boilers the smallest flue will be 1/5 of this size or

$$\frac{28.5}{5} = 5.7 \text{ square feet.}$$

Make this flue 2 x 3 feet.

The remaining flues will vary proportionally between these sizes.

2. Smoke Flues: Quantity of air required at 500 F., was found assuming that the volume of air are proportional to the absolute temperature, that is

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

And since the value of V_1 = 57 000 cubic feet

$$T_2 = 500 + 460 = 960°$$

$$T_1 = 60 + 460 = 520°$$

The value of V_2 will be

$$V_2 = 57000 \times \frac{960}{520} = 108\ 000 \text{ cubic feet per minute}$$

At a velocity of 2000 feet per minute the required area will be

$$\frac{108\ 000}{2000} = 54 \text{ square feet}$$

Make flue 6 x 9 feet.

The smallest flue will be $\frac{54}{5}$ = 10.8 square feet.

Make flue 3 x 4 feet.

The remaining flues will vary proportionally between these sizes.

SIZE OF PIPES: 1. Main Steam Supply Pipe Connecting the Header with Each of the Engines: The pipes were calculated by means of the formula given by Mr. F. Koester in his book on "Steam Power Plants" (page 182):

$$Q = 3000 \frac{p\, d^5 D}{L} \qquad (1)$$

where d = Diameter in inches

L = Length of piping in feet

p = Loss of pressure thru friction etc.

D = Density of steam in pounds per cubic feet

Q = Pounds of steam per hour

To allow for losses due to valves, connections and bends, a correction factor is applied in the form of a certain additional length of pipe for each such obstruction. The following table gives the number and kind of obstructions in each pipe with corresponding correction factor and equivalent length of pipe:

Obstructions	Number	Correction Factor	Equivalent Length
Globe valves	3	5 d	15 d
T's (not change in direction)	2	1.6 d	3 d
L's	1	5 d	5 d
Total			23 d

As the engines are to be used for a relatively short time a high per centage of drop may be used and in this case 5 per cent will be assumed .

In the present instance:

L (corrected) =(86 + 23 d) feet

$$p = \frac{150 \times 5}{100} = 7.5 \text{ pounds.}$$

D = .367 pounds.

Q = 100 000

Equation (1) being of the fifth power is best solved by trying successive values of d, until a value is obtained fulfilling the conditions. In this manner the proper value of d was found to be ten inches. The value assumed for the diameter seems to be rather small, but is not, because the consumption of steam does not take place at the end of the pipe only, but along the whole length, making the drop in pressure at the first engine much less than 6.5 per cent , the value obtained by using the ten inch pipe instead of the large one required to obtain the 5 per cent drop assumed; and of course there is no question as to the lower drop in the other two pieces of pipe connecting the second and third engine, since, as will be seen below, the diameter of the pipe used for these engine is a little larger than necessary. These values, as obtained from a table on page 181 of the book mentioned, are nine and seven inches respectively; but since the engines require a nine inch steam pipe (see engines) , a ten inch pipe will be used from the first to the second engine, and a nine inch pipe from the second to the third.

In order to find out what thickness of pipe - standard or special - should be used, the following formula, given on page 199 of the book above referred to was used

$$t = \frac{p\ d\ s}{T}$$

were t = thickness of pipe in inches.

p = pressure in pounds per square inch.

d = initial diameter in inches.

T = tensil strength of the matirial.

S=factor of safety.

Using wrought iron pipes, whose tensile strength is 50 000 pounds per square inch, and a factor of safety of 8, with p = 150 pounds and d = 10 inches, the thickness was found to be

$$t = \frac{150 \times 10 \times 8}{50\ 000} = .24 \text{ inches.}$$

The thickness of a 10 inches standard wrought iron pipe given by the hand book of the Cambria Steel Company is .36 inches, which is sufficiently heavy for our purpose. The complete data for this piping will be found on page 51.

2. Exhaust Main: The size of this pipe should vary according the quantity of steam that is to flow thru it, that is, at the remotest engine the cross section of the pipe must be large enough to leave a free path for the exhaust steam of one engine, at the second, large enough for the exhaust steam of two, etc. , but as pipes of this size are rather expensive, the approximate size of them was found, the diameter of the pipes connecting the engine with the exhaust being 14 inches (given by catalog). This was accomplished by making use of the following formula, given by Mr. Gebhardt in his book on "Steam Power Plants',page 570:

$$N_1 = d^{5/2} \div d_1^{5/2}$$

where N_1 = number of pipes of diameter d_1 equal in capacity to a pipe of diameter d , d and d_1 being in inches.

Taking d as the largest pipe, $N_1 = 3$

$d_1 = 14$ inches

and substituting in the above formula

$$3 = \frac{d^{5/2}}{14^{5/2}}$$

Whence $d = 21.7$ inches

or, say $d = 22$ inches.

d being known, the diameters of the smaller pipe were found by using the table on page 181 in Koester. The diameters thus obtained were 16 and 14 inches.

3. Header: The diameter of this pipe was found by applying the same principle above used, that is:

$$Q = 3000\sqrt{\frac{p\ d^5\ D}{L}}$$

This line of pipe has

Obstructions	Number	Correction Factor	Equivalent Length
Globe valves	5	5 d	25 d
T's (not change in direction)	7	1.6 d	11.2 d
L's	2	5 d	10 d
Total			46.2 d

The actual length of the pipe being 95 feet, the total equivalent length is

$$L = 95 + 46.2\ d$$

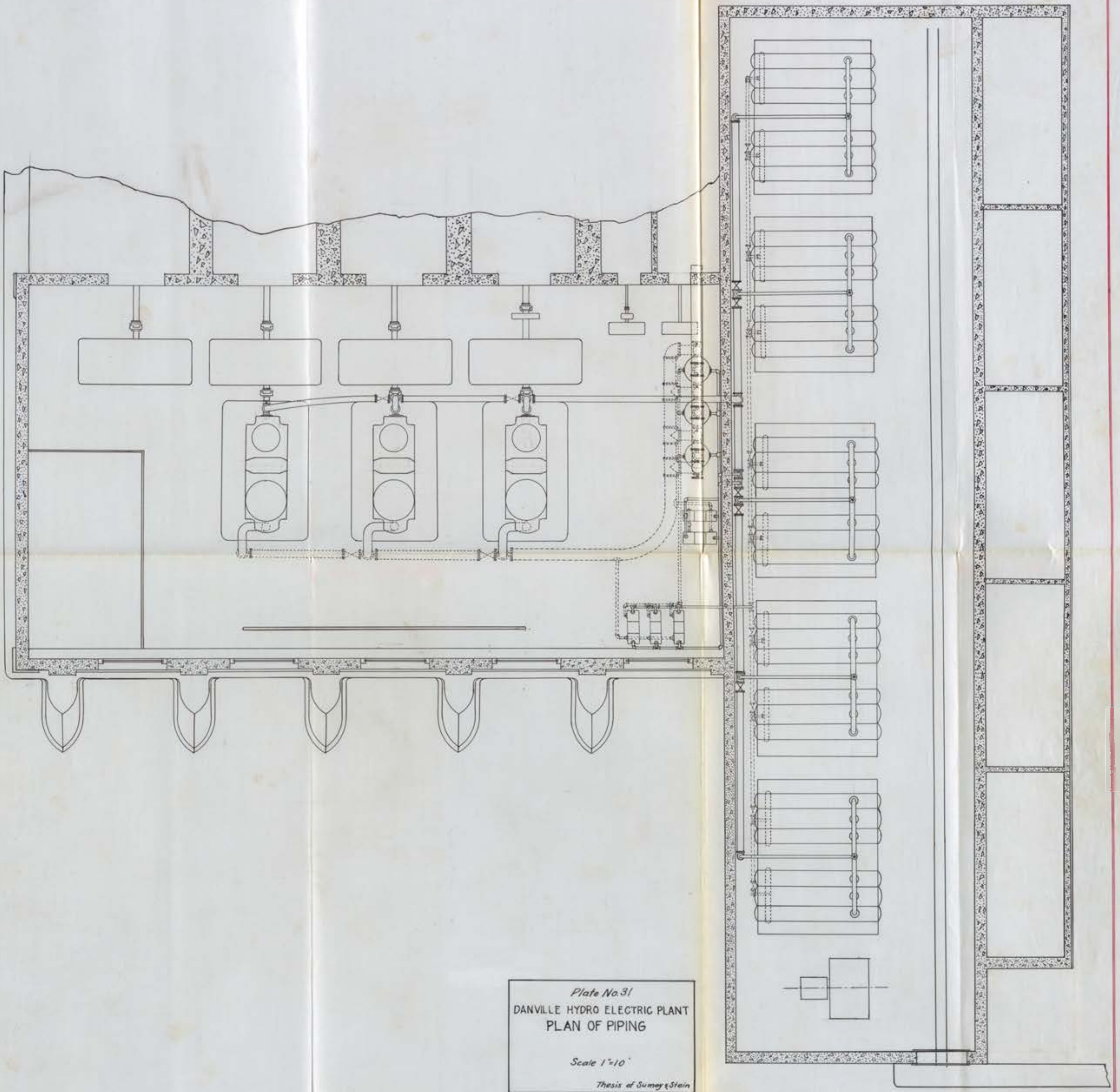


Plate No. 31

DANVILLE HYDRO ELECTRIC PLANT

PLAN OF PIPING

Scale 1" = 10'

Thesis of Sumey & Stein

Item	WEIGHT	COST $
For main steam pipe:		
Pipe, 63 feet of 10 inch standard	2520	268.00
Pipe, 23 feet of 9 inch standard	775	78.00
Globe valves, 2 - 10 inch		175.00
" " 1 9 "		85.00
T's, 1 - 10 x 9 x 10 inch		39.00
" 1 - 10 x 10 x 9 "		39.00
L's, 1 - 9 x 9 inch		20.50
For main exhaust pipe:		
Pipe, 66 feet of 22 inch standard	5640	500.00
" 22 " " 16 " "	1360	110.00
" 22 " " 15 " "	1270	106.00
Globe valves, 1 - 16 and 1 - 14 inch		250.00
T's, 1 - 22 x 22 x 22 inch		173.00
3 - 22 x 9 x 22 "		519.00
1 - 22 x 14 x 16 "		173.00
1 - 16 x 14 x 14 "		102.00
L's, 1 - 14 x 14 "		37.00
From main exhaust to heaters		
Pipe, 19 feet of 15 inch standard	1100	78.00
" 35 " " 22 " "	2020	266.00
Glŏbe valves, 3 - 14 inch		366.00
" " 1 - 22 "		320.00
T's, 3 - 22 x 22 x 22 "		519.00
L's, 1 - 22 x 22 inch		102.00
From heater to heater exhaust:		
Globe valves, 3 - 14 inch		366.00

ITEM	WEIGHT	COST
From above		
Steam pipe to feed water pumps:		
Pipe, 77 feet of 2.5 inch standard	442	92.00
Globe valves, 3 - 2.5 inch		20.70
T's, 2 - 2.5 x 1.5 x 2.5 inch		10.60
L's, 3 - 2.5 x 2.5 inch		9.600
1 - 2.5 x 1.5		3.20
Steam pipe to feed suction pumps:		
Pipe, 43 feet of 2.5 inch standard	247	52.00
Globe valves, 2 - 2.5 inch		13.80
T's, 1 - 2.5 x 1.5 x 2.5 inch		5.30
L's, 2 - 2.5 x 2.5 inch		6.40
1 - 2.5 x 1.5 "		3.20
Exhaust pipe from the feet water pumps;		
Pipe, 24 feet of 3 inch standard	181	35.00
Globe valves,3- 3 inch		28.80
T's, 2 - 3 x 2 x 3 inch		14.00
L's, 2 - 3 x 3 inch		7.80
Exhaust pipe from suction pumps:		
Pipe, 10 feet of 2.5 inch standard	57	12.00
Globe valves, 2 - 2.5 inch		13.80
T's, 1 - 2.5 x 2 x 2.5 inch		53.00
L's, 2 - 2.5 x 2.5 inch		6.40
Header:		
Pipe, 95 feet of 8 inch standard	3040	295.00
Globe valves, 5 - 8 inch		242.00
Total		

ITEM	WEIGHT	COST
From above		
T's, 3 - 8 x 4 x 8 inch		72.00
2 - 8 x 2.5 x 8 inch		48.00
1 - 8 x 10 x 8 "		24.00
L's, 2 - 8 x 4 inch		26.00
Pipe from boiler to header:		
Pipe, 29 feet of 4 inch standard	255	36.00
Globe valves, 1 - 4 inch		14.00
L's, 1 - 8 x 4 inch		13.00
Trap for 800 square feet drainage, one		25.00
Separators for 1100 horse power engine, three		
Five pumps		
Three feed water heaters		3800.00

Assuming drop in pressure at the main steam pipe 3 per cent

$$p = \frac{150 \times 3}{100} = 4.95 \text{ pounds.}$$

$$D = .367$$

$$Q = \frac{100000}{5} = 30\ 000$$

Let d = 8 inches. By substituting in the above formula

$$30\ 000 = 3000 \sqrt{\frac{4.95 \times 8^5 \times .367}{95 + 46.2 \times 8}}$$

it gives 160 in the first member and 180 in the second. As this is a close approximation we shall use the size of pipe assumed. The complete data for this pipe is found on page 51.

4. Other pipes: By the method illustrated in the preceding pages the diameter, and thickness of the remaining pipes in the power plant were calculated, a table of which will be found on pages 51-3 containing all data relating to steam and water pipes.

BOILER FEED PUMPS: The boiler feed water pumps are of the style known as the "Duplex Boiler Feed Pump" made by Fairbanks, Morse and Company. The capacity of each pump is 66 gallons per minute and the dimensions are as follows:

Diameter of steam cylinder	6 in.
Diameter of pump cylinder	6 in.
Stroke	10 in.
Pressure pumped against	150 pounds
Capacity in gallons per stroke	.85
Size of boiler supplied	1100 H. P.
Diameter of steam pipe	1 1/2 inch
" " exhaust pipe	2 "

Diameter of suction pipe	4 inch
" " discharge pipe	3 "
Floor space occupied	72 x 23 inches

Three pumps are needed to pump the water from the heater to the boilers, while two pumps are provided to pump water from the river to replace losses of feed water due to incomplete condensation of exhaust steam.

The suction pipe leading from the river is six inches in diameter and the main feed water pipe is five inches in diameter .

TRAPS: In order to drain the long exhaust pipe a trap is located at one end of it. The size of the connection is 3/4 inch; the maximum discharge of condensed water per minute is 5 pounds; the greatest surface to which it is applied 800 square feet.

SEPARATORS: A separator of the Cochrane, vertical receiver type, is placed in the pipe connecting the main steam pipe with the engine. The dimensions for the separator were obtained from catalogue Number 15, Harrison Safety Boiler Works.

HEATERS: As the character of the power plant does not require that all the boilers work at the same time, except at infrequent intervals, the heater capacity has been divided into as many heaters as engines, viz: three. The kind of heater used is the Brownell type. They are selected so as to provide enough feed water for three 1100 H. P. engines; the dimensions of each heater being:

Diameter	54 inches
Height	12 feet
Exhaust connection	14 inches
Cold water inlet connection	2 1/2 "
Hot water inlet "	4 1/2 "
Weight	2500 pounds.

TRANSMISSION LINE: The transmission line is to be 7900 feet long, extending from the plant alomg Third street to its intersection with the interurban railway, along the interurban to Bridge street, and thence across the valley of the North Fork to Mill street, at which point it is to be subdivided in the manner best fitted for distribution of the current. The line is to be of the three phase system, 6600 volts, designed to carry the total output of the plant, and having a power factor of about .80 on account of the arc lamps and motors.

Taking into consideration only one leg of the circuit, to simplify the problem, the E. M. F. between each wire and neutral is

$$\frac{6600}{\sqrt{3}} = 3810 \text{ volts.}$$

The energy delivered by each leg is

$$\text{K. W.} = \frac{\text{Total output of the plant}}{\text{Three}}$$

$$= \frac{3140}{3} = 1046.66 \text{ K. W.}$$

The apparent energy delivered by each leg is

$$\frac{1046.66 \text{ K.W.}}{.80} = 1\ 308\ 000 \text{ watts}$$

and the current in each leg is

$$\frac{1\ 308\ 000}{3810} = 343 \text{ amperes}$$

To determine the size of conductors necessary, we must assume an I R drop in each leg. Some of the conditions that govern this assumption are: first, that the I R drop should be small, because the water power available is not in excess of the demands; second, that the distance is relatively short; and third, that, as this plant will necessarily compete with the one already installed, the service must be at least as good as that of the latter. For all these reasons we assumed an I R drop of seven per cent of the voltage in each leg. This drop is equal to

$$\frac{3810 \times 7}{100} = 267 \text{ volts.}$$

And the resistance R is

$$R = \frac{267}{343} = .777 \quad \text{ohms per 7920 feet}$$

Then the ohms per foot will be

$$R_1 = .000\ 009\ 82$$

In order to get the circular mils the following principle is used:

$$R = K \frac{1}{c.\ m.} \qquad (1)$$

where R = total resistance of circuit .777 Ohms

K = resistance of one milfoot @ 20° C. 10.35

1 = total length of line (one leg) 7920 feet

c. m. = circular mils that the main has to have.

Substituting values in equation (1) and solving for c. m.

$$c.\ m. = \frac{10.35 \times 7920}{.777} = 105\ 500 \quad c.\ m.$$

which corresponds to a wire # 0 A. W. G.

The weight of this wire for the three legs is 7560 pounds.

Actual Voltage at the Generators: In order to find at what voltage the generators must run in order to maintain the proper voltage on the line, the following calculation was made:

First the self-inductance of the line was found. This was ac -

complished by subtituting in the following formula, given by Francis B. Crocker on his book on "Electric Lighting", page 129.

$$L \text{ (per foot)} = \left(12.24 + 140.3 \log \frac{2A}{d} \right) 10^{-9} \qquad (2)$$

where L = is the self-induction in henrys per foot of each wire

A = is the interaxial distance between two wires

d = the diameter of the cable.

The Standard Hand-book gives distance A = 18 inches or 1.5 foot for a voltage of 16 000 volts, as this is the lowest voltage for which this book has tables, and this value being a reasonable one for our case(6600 volts) it will be used:

$$\text{Diameter of wire} = \frac{105\ 500}{1000} = .325 \text{ inches}$$

or

$$d = .0275 \text{ feet}$$

Substituting in equation (2)

$$L = \left(12.24 + 140.3 \log \frac{2 \times 1.5}{.0275} \right) 10^{-9}$$

$$L = 301.24 \times 10^{-9} \text{ henrys per foot}$$

and for 7920 feet

$$L = .002385 \text{ henrys.}$$

Now, making use of the resonance method we find the capacity of the line ; this method is applied as follows:

It has been found that the fundamental frequency f^1 of a line in resonance is

$$f^1 = \frac{1}{4\ L\ C} \qquad (3)$$

where L = same as above

C = capacity

f = fundamental frequency.

And also that the wave length of the line when in resonance is equal to four times the length of the line

Hence
$$f^1 = \frac{\text{Velocity of Electric waves}}{4 \times \text{Length of Line}}$$

Velocity of electric waves = 186 000 miles per second

Then
$$f^1 = \frac{186\ 000}{4 \times 1.5} = 31\ 000 \text{ waves per second}$$

Whence, by substituting the value in equation (3) and solving for C, the capacity of the line is found

$$C = \frac{1}{(4 \times 31\ 000)^2 \times .002385} = .000\ 000\ 272 \text{ Farads}$$

or
$$C = .0272 \text{ M. F.}$$

Now, since we know the value of the self-induction (= L = .00191 henrys) the value of the reactance of the circuit may by found by means of equation

$$X = 2 \pi f L \qquad (4)$$

where X = reactance of the circuit

f = frequency of the cicuit (60 cycles)

Then
$$X = 2 \times 3.14 \times 60 \times .002385$$

$$X = .900 \text{ Ohms.}$$

and from above
$$R = .0854 \text{ Ohms.}$$

Using all the above found data, the voltage at which the gener - ators have to work can be obtained. In doing this we assume the capacity, inductance, and resistence to be distributed in the line as shown in the following sketch.

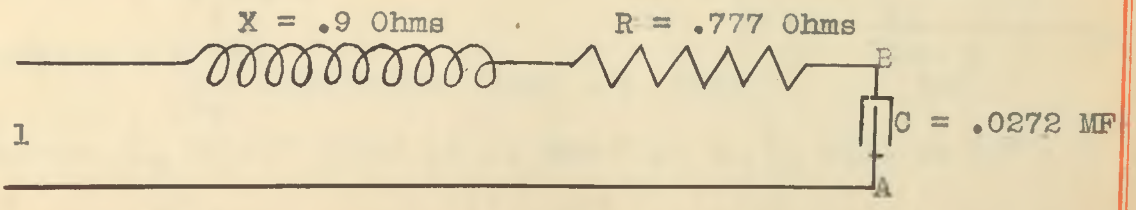


Fig. 1

A more accurate method would be to consider capacity at the middle of the line, but for such a short line as this the error is small if we consider the capacity concentrated at the end of the line.

Then, at the receivers end the conditions are:

E. M. F. = 3810 volts

K. W. = 1046.66 K. W.

P. F. = .80

Current = 343 amperes

The E.M.F. in phase with I (current) will be

$e' = 3810 \times .80 = 3050$ volts

and the E. M. F. 90° ahead of I will be

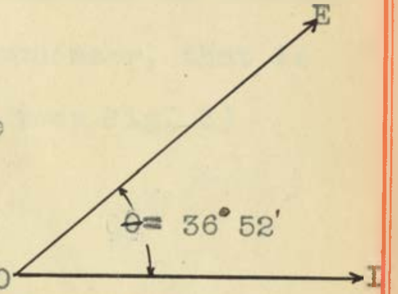


Fig. 2

$e'' = 3810 \sin \theta = 3810 \times .59995$

$e'' = 2285$ volts.

Then, E. M. F. in the circuit

$$E = 3050 + j\ 2285 \qquad (5)$$

In order to find the current through the condenser it is convenient to find the susceptance of the circuit, and this is equal to "b".

and $$b = 2\pi f C \times 10^{-6}$$

where b = a factor which multiplied by the E. M. F., gives the component of I, which is 90° ahead of E.

Then, $$b = 2 \times 3.14 \times 60 \times .0272 \times 10^{-6}$$

or $$b = .000\ 01025$$

Whence $$I_c = E\ b$$

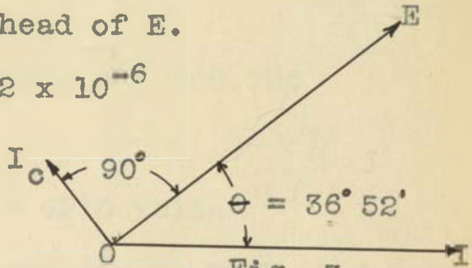


Fig. 3

or multiplying b x (5)

$$I_c = .000\ 01025\ (3050 + j\ 2285) \qquad (6)$$

But since I_c is 90° ahead of I, see Fig. 3, I_c will be 90°

ahead of E, and equation (6) becomes

$$I_c = j\ .000\ 010\ 250\ (3050 + j\ 2285)$$

or $$I_c = .0313\ j + j^2\ .02285$$

but we know that j^2 is equal to -1, then,

$$I_c = -.02285 + j\ .0313$$

This is the current from A to B; then it remains to get the current from B to C. Let this current be = I_t

This current evidently will be equal to the current at the end of the line plus j times the current thru the condenser, that is the vectorial addition of the current I_e and I_c (see Fig. 3)

or $$I_t = 343 + (-.02285 + j\ .0313)$$

whence $$I_t = -342.997 + j\ .0313$$

And then the drop from B to C will be

$$\text{drop} = I_t\ (R + j\ X)$$

$$= (342.997 + j\ .0313)(.777 + j\ .9)$$

reducing we get

$$\text{drop} = 266.9 + j\ 308.724 + j^2\ .02817$$

or $$= 267.872 + j\ 308.724 \qquad (7)$$

And then the E. M. F.. at the generator will be equal to voltage at B plus the drop from B to C.

Letting E_g = the E. M. F. of generator

$$E_g = \text{equations}(5) + (7)$$

substituting $$E_g = (3050 + j\ 2285) + (267.872 + j\ 308.724$$

or $$E_g = 3317.87 + j\ 2593.72$$

whence $$E_g = \quad 3317.87 + 2593.72 \quad = 4210 \text{ volts}$$

This is voltage between wire and neutral; and the E. M. F. between wires will be

$$V\ 3\ E_g = V\ 3 \times 4210 = 7280 \quad \text{volts}$$

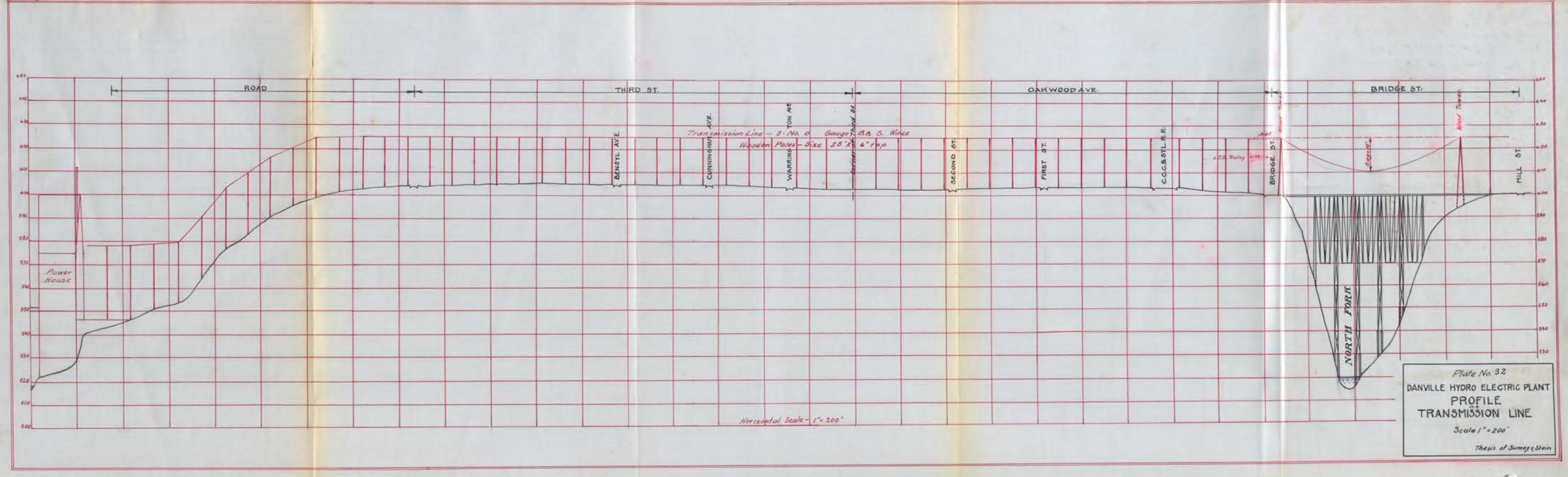


Plate No. 32

DANVILLE HYDRO ELECTRIC PLANT

PROFILE of TRANSMISSION LINE

Scale 1" = 200'

Thesis of Sumay & Stein

And since the voltage at the distribution end is 6600 volts, the drop is

$$7280 - 6600 = 680 \text{ volts}$$

or practically 10 per cent drop, which is satisfactory.

The line is to be of the usual type, supported on wooden poles spaced 100 feet apart. The length of poles is 25 feet, top diameter, 6 inches, and each pole is provided with a cross arm and three insulators. The North Fork is to be crossed by suspending the wire from a steel cable supported on two wooden towers, span 800 feet.

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